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# THE ECONOMICS OF ELECTRIC COOKING

BY
P. W. GUMAER
*Instructor in Electrical Engineering*

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# The Economics of Electric Cooking

## INTRODUCTION

The present status of electric cooking might be compared in a way with the condition of electric lighting about 1890. Electric lighting had then passed beyond the experimental stage and was used commercially but no exhaustive study had been made of the science of illumination with a view to obtain the greatest efficiency. Today, electric cooking has passed beyond the experimental stage and is used commercially, but as yet no study has been made of the variable conditions affecting this work, or the combination which will produce the greatest efficiency.

The first electric light fixtures were obtained by wiring the gas fixtures then in general use. Afterwards special types of fixtures were developed which were more adapted to the use of electricity. Similarly, the first electric ovens were obtained by replacing the gas burners of a gas oven with electric heating coils. Some further improvement has been made by adding heat insulation, but as yet little attention has been given to the proper conditions of cooking which make for greatest convenience and economy in operation. With inefficient stoves and cheap fuels the need of such an investigation has not been apparent. Since in a coal range only a very small percentage of the heat energy in the fuel is absorbed by the food, it makes but little difference whether a particular article of food is cooked for half an hour at 200°C. (392°F.) or for one hour at 150°C. (303°F.) as long as the final quality of the food is satisfactory.

It was the purpose of the investigations which form the basis of this article to study the operation and the design of electric ovens with the view to determine some of the factors which will increase the economy and hence the popularity of electric cooking. While the actual results here presented are not as definite and illuminating as hoped for, yet it is believed they will not be without practical value as a contribution to what is a very complex subject.

Particular attention is called to the fact that much of the information contained herein is made easily available to the understanding by the use of plotted curves.

## DESCRIPTION OF OVENS USED IN THE TESTS

In order to determine the amount of energy used in electric cooking and the best methods of preparing various articles of food for an electric oven, tests were made on three commercial and several

experimental ovens. Each commercial oven was selected as representing a general type of electric oven in use for domestic cooking.

Fig. 1

Fig. 1 shows a large range suitable for a good sized family. The inside dimensions of the oven are 18 inches by 12 inches by 12 inches. Two heating units are used, one in the top and one in the bottom of the oven. Each unit consists of two heating coils controlled from a snap switch on the front of the oven so as to consume 220, 440, or 880 watts continuously. From one to two inches of mineral wool is used as heat insulation. The outside surface of the oven is blued steel and it is finished with nickeled legs and trimmings. The oven door is 12 by 18 inches and 1.5 inches thick. It fits tightly and clamps securely in place when shut. Three heating units are also placed on top of the range for cooking not done in the oven. Fig. 2 is a cross section of the oven thru the center, showing the position of the heating coils and the thermo-couple used to measure the temperature in these experiments.

Fig. 3 shows a small, well-insulated oven (No. 2) suitable for a small or medium-sized family. The inside dimensions of the oven are 9.5 inches wide, 10 inches deep, and 12 inches high. The inside finish is seamless drawn aluminum and the outside is blued steel with nickeled trimmings. Two and one-half inches of mineral wool is used for heat insulation. An ironclad heating element is placed in the bottom of the oven. This heating element consumes continuously 500 watts when connected to a 110 volt circuit. The heat cannot be turned

partly off as there is only one heating element. There is no heating unit in the top of the oven. Underneath the oven is an automatic temperature control which may be set at various values by means of a dial. The dial is graduated in arbitrary numbers from 1 to 11. When

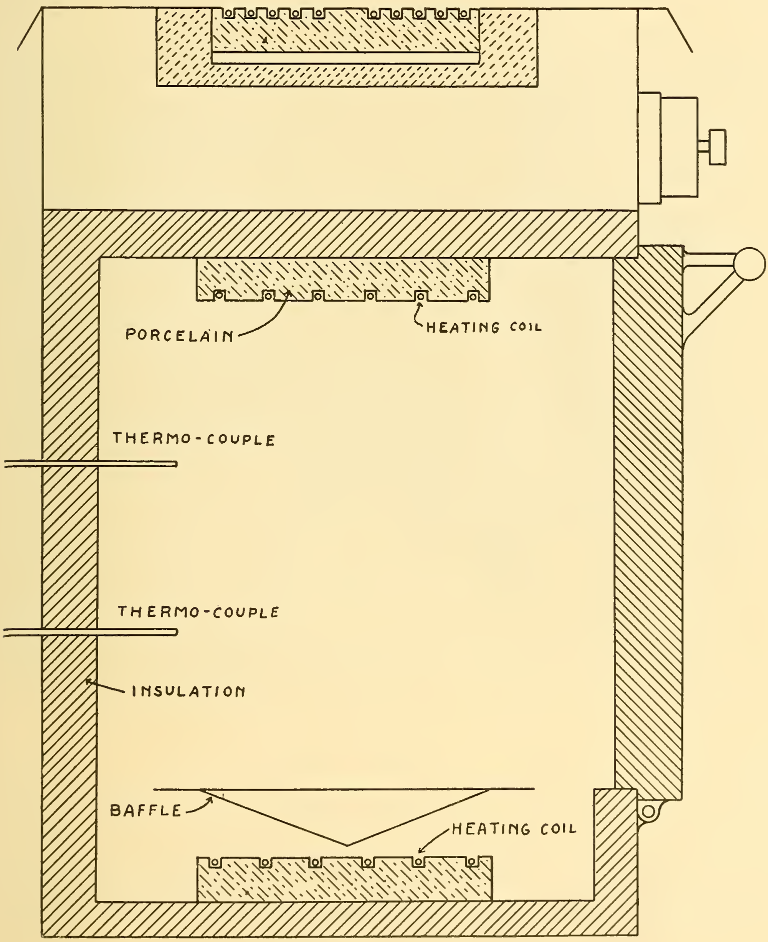


FIG. 2 CROSS-SECTIOIN OVEN NO. 1

the handle of the dial is set at a given number, a thermostat will open the circuit of the heating element as soon as the inside of the oven has reached a temperature corresponding to the given number. As the oven cools, the thermostat must be reset by hand by pushing the handle

of the dial. Fig. 4 is a cross section of the oven thru the center showing the position of the heating coil and the thermo-couple used in the experiments.

Fig. 5 shows oven No. 3, one of the well-known makes of fireless cookers with a heating element placed underneath the inner lining.

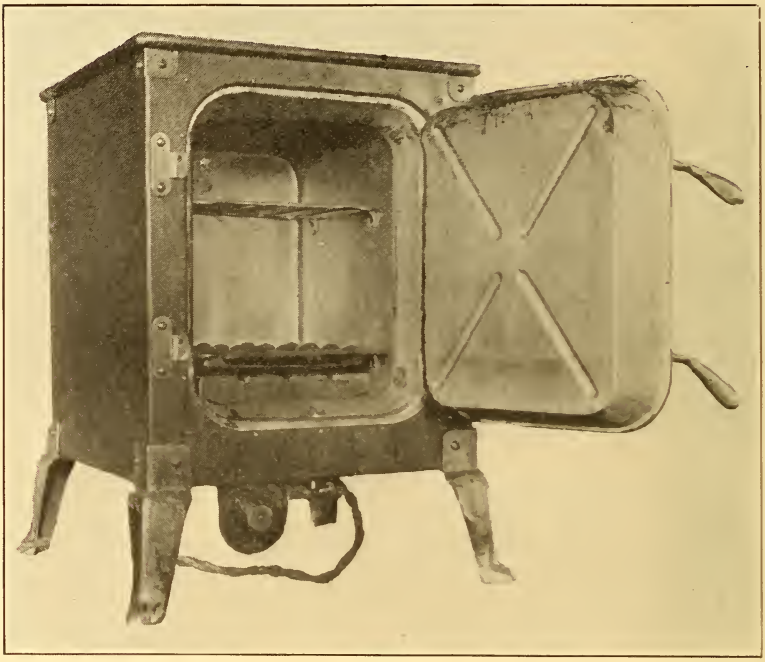

Fig. 3

The inside dimensions are 10.5 inches deep and 11.5 inches in diameter. The inside lining is seamless aluminum and the outside finish is varnished oak. The sides and bottom are insulated with powdered kieselguhr, while the cover is insulated with granulated cork. Fig. 6 is a cross section of the oven showing the heating coil and thermocouple. This oven uses 500 watts on 110 volts. There is no method of turning the energy partly off.

Oven No. 4 was built by the Engineering Experiment Station. The inside dimensions were the same as oven No. 2. A 440, 880-watt heating unit was placed in the bottom of the oven and a 440-watt unit in the top as shown in Fig. 7. Sheet iron was used for the inside lining of the oven. A 4-inch layer of a commercial brand of diatoma-

ceous insulating brick was used for insulation. Later four inches of cork board was added as shown in the drawing. This was put on with cement and no outside covering was used except on the front and the door, which were covered with wood.

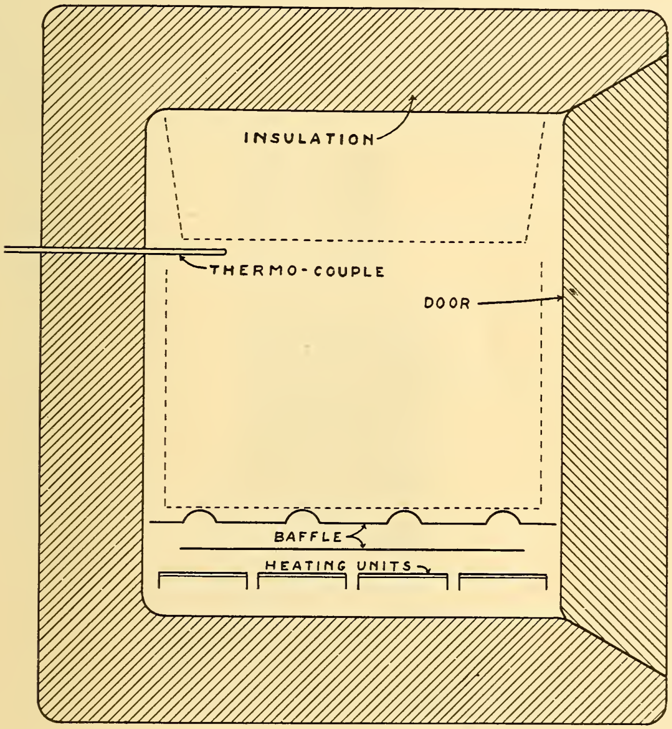


FIG. 4 CROSS-SECTION OF OVEN NO. 2.

## APPARATUS USED

The energy used was measured by means of indicating watt meters calibrated by comparison with Weston laboratory standards, and by an induction watt-hour meter calibrated at frequent intervals by comparison with a rotating standard.

The temperature of the ovens was measured by means of copper-constantan thermo-couples with which an accuracy of 0.1 degree is obtainable when used below 360°C.[1] (680°F.). A Siemens-Halske indi-

1. Adams and Johnson. Am. Jour. of Science, June, 1912.

cating galvanometer and a Bristol recording galvanometer were used to determine the e.m.f. of the thermo-couples. The recording galvanometer traced a curve by intermittent contact on a circular smoked chart. Both the indicating and the recording galvanometer were calibrated for the copper-constantan thermo-couples by means of mercury thermometers which had been certified by the Bureau of Standards. The thermo-couple and the thermometer were immersed in an oil bath which was slowly heated and carefully stirred. Simultaneous readings were taken of the galvanometer and the thermometer. Fig. 8 shows a

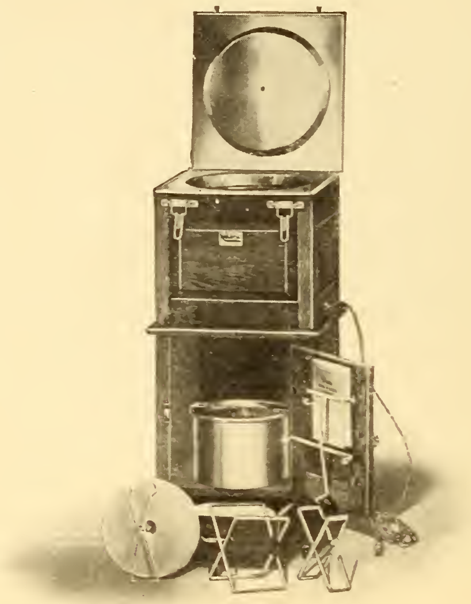

Fig. 5

diagram of the connections used for the galvanometers and thermocouples.

In the oven the wires of the thermo-couple were enclosed in a glass tube and separated by mica. Outside the oven they were enclosed in rubber tubing. The cold junction was kept at 0°C. (32°F.) by immersion in ice water.

In oven No. 1 an extra thermo-couple was inserted for measuring the internal temperature of the food. The wires entered the oven thru two glass bushings and were left bare except for a 3-inch glass tube at the end which was inserted in the food. The wires were long

enough so that after the food was cooked it could be placed on a shelf just outside the oven to cool without removing the thermo-couple from the food. In order that the wires would not short circuit either on themselves or on the lining of the oven all the slack was pulled outside the oven.

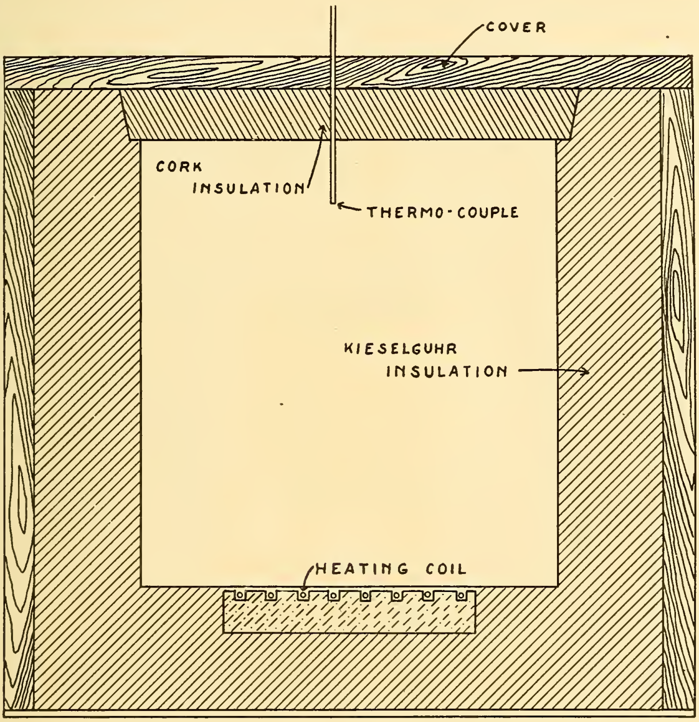


FIG. 6 CROSS-SECTION OF OVEN NO. 3

## THEORY AND PURPOSE OF COOKING

In order to understand some of the problems which must be worked out before an ideal electric cooking device can be perfected, a word about the purpose of cooking food will not be out of place. The objects of cooking food are, briefly: (1) to render it more digestible so that the nutrient parts can be easily absorbed by the digestive organs; (2) to render it more appetizing by improving its appearance and developing in it new flavors; (3) to sterilize it to some extent thus delaying incinient putrefaction. The relative importance of these

objects depends upon the article of food which is to be cooked. For instance, in cooking animal foods the most important objects to be attained are to improve the flavor and appearance and to sterilize them. In fact, the cooking of animal foods such as meat, eggs, and fish which are rich in proteids actually decreases their digestibility. This is true at least of the chemical processes of digestion. The in-

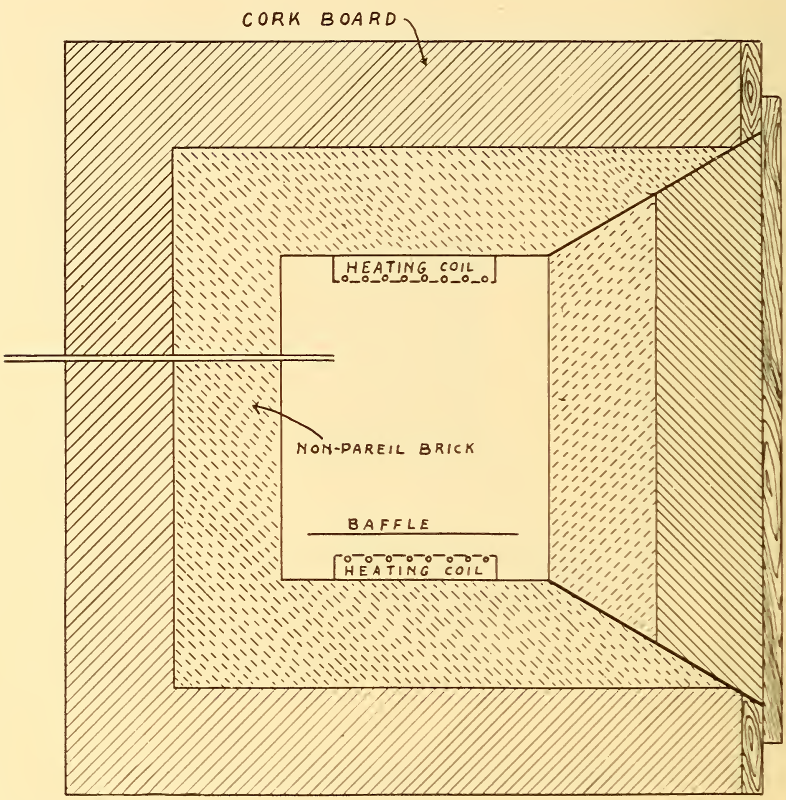


FIG. 7 CROSS-SECTION OVEN NO. 4

creased attractiveness, however, of well-cooked food may render it indirectly more digestible by causing a greater flow of the digestive juices.

The effects of applying heat to various foods can be more easily understood by first considering the effect of heat on the various chemi-

cal constituents of which protein, starch and fat are the most important. The effect of heat on the protein of foods is to coagulate it. This change occurs at the comparatively low temperature of 75°C. (167°F.). If the temperature is increased much above this point the protein tends to shrink and harden, and the digestibility of the food of which it is a part is proportionately lessened. This fact can be easily demonstrated in the case of the white of an egg. If an egg cooked for ten minutes in water at a temperature of 75°C. is compared with one cooked in the ordinary way, that is, for three minutes in boiling water, it will be found that the albumin of both are solid thruout, but in the case of the former it will consist of a tender jelly, whereas in the boiled egg it will be dense and almost leathery.

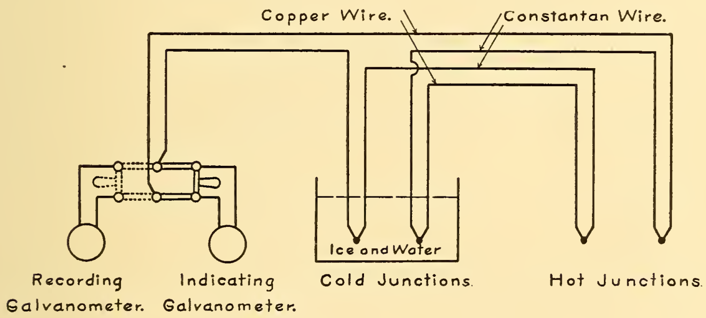


FIG 8. CONNECTIONS OF THERMO-COUPLES AND GALVANOMETERS

The investigations of Meyer,[1] Harcourt,[2] and Day [3] demonstrate that starch consists of microscopic grains or cells which are but slightly soluble in cold water. These grains are composed of layers. The inner and outer layers have distinct properties. The inner layers, called blue amylose because of the color which they give with iodine, are very slowly digested in the raw state. They take up water at from 60° to 80°C. (140° to 176°F.) and form a sticky collodial substance known as starch paste, in which form the inner portion is very easily digested. Long boiling to the extent of three hours does not make it more digestible. The outer layers of the starch (called red amylose) give a red color with iodine, and are more difficult of digestion or change in water than the inner portion of the starch grain. When starch paste is made without boiling, the outer layer stretches tho it

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1. Untersuchungen über die Stärkehörner, Jena, 1895, p. 107.
2. Ann. Rpt. Ontario Ag. Col. and Exp. Farm 32, p. 63.
3. U. S. Dept. of Agr. Bul. 302.

does not break. In this condition it is easily permeable and does not interfere with the more rapid digestion of the inner portion. When starch paste is boiled Doctor Day found that a more homogenous tho not more digestible paste results. Dry heat at 150°C. (302°F.) or higher converts starch into a soluble form, and finally into dextrin. This change occurs to a limited degree in the crust of bread and in the making of toast.

In many vegetables and unground cereals the starch grains are enclosed in woody, fibrous, or cellulose walls which are but slightly affected by the digestive juices. The effect of cooking by the application of moist heat causes the starch grains to swell and to finally rupture the cellulose walls. This process occurs at temperatures much below the boiling point of water as shown by the values [1] given in Table I.

Table I.

| | |
|---|---|
| Oats | 85° Cent. (185°F.) |
| Barley | 80° Cent. (176°F.) |
| Wheat | 80° Cent. (176°F.) |
| Rice | 80° Cent. (176°F.) |
| Maize | 75° Cent. (167°F.) |
| Potato | 65° Cent. (149°F.) |

Since the fats of food are apparently but slightly affected by cooking,[2] their consideration is not of as much importance as protein or starch. The only change that has been detected in the composition of fats in cooking is a tendency to form free fatty acids at high temperatures (250°C.) (482°F.) which are thought to be irritating to the stomach.

The ideal preparation of food for human use requires that the nutrient which it contains shall be utilized to the fullest extent. Not only should the food be in such a state that the digestive juices can best act on it, but these digestive juices should be properly stimulated to do their work, by improving the taste or flavor of the food.

The present day problem is to determine the methods of cooking which will yield the most in nutrition and flavor with a minimum expenditure of fuel and labor. The solution of this problem will require careful research by the physiological-chemist, the domestic scientist and the manufacturer of cooking apparatus. Taking into consideration the results of experiments on the digestibility of foods cooked in various ways, the problem of the domestic science department is to definitely determine the range of temperatures and the

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1. Sykes, Principles of Brewing, p. 70.
2. U. S. Dept. of Agr. Farm Bul. No. 526, p. 14.

time of cooking at each temperature for all classes of food. Effects of quality and proportion of ingredients, size of utensils, and other variables must be studied so that definite rules and tables can be worked out giving the most desirable times and temperatures of cooking any article of food.

The problem of the electrical engineer is to determine from the range of temperatures for cooking any given article of food, the particular temperature which is the most economical. He must also perfect an electric cooking apparatus which will maintain the desired temperature with a minimum amount of attention, and which will be low in first cost and economical in operation.

## LOSSES OF ENERGY IN ELECTRIC OVENS

During the last century there has been a great advancement in the methods of applying heat to food. Each improvement has resulted in less of the heat energy being wasted and in more being absorbed by the food. Each step, from the open fireplace to the coal range, to the gas stove, and finally to the electric oven has been marked by the use of more expensive fuel, greater heat efficiency, and better control of the heat.

Except in a few localities, for the same number of heat units delivered at the meter, electricity is more expensive than gas or coal. Hence, it is only by studying carefully the most economical features of design and operation of electric cooking apparatus that electricity will be able to compete with gas and coal. A study of the heat losses in cooking is, therefore, of considerable importance to the designer of electric cooking apparatus.

**Convection and Radiation Losses.** If an electric oven is supplied with electric energy at a constant rate, say 1000 watts, the temperature of the oven will at first increase rapidly and then more slowly until it finally reaches a constant value. From the law of the conservation of energy it follows that if there is no food in the oven, the same amount of energy is lost into the room that is supplied by the heating coil. This heat is lost in two ways,—by radiation and by convection.

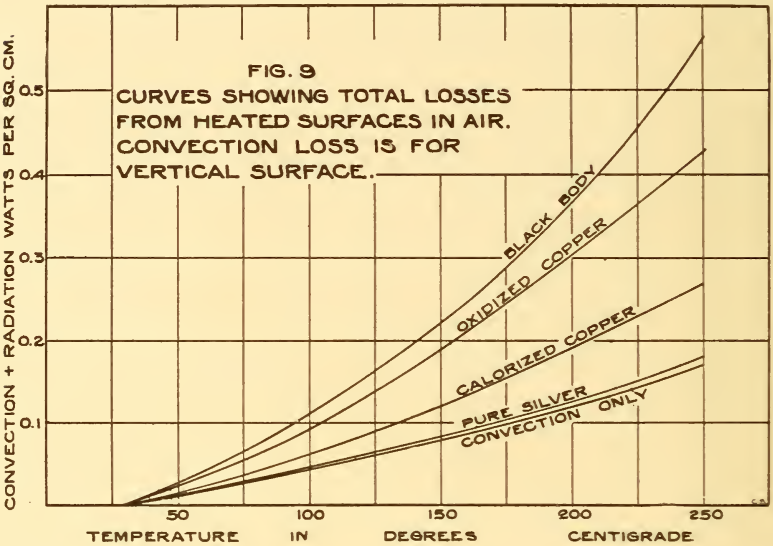
The radiation loss consists of waves of energy similar to light waves but of different length. The amount of the energy radiated depends upon the nature of the surface, its temperature, and the temperature of the room. It is independent of the shape of the radiating surface. The convection loss, however, depends upon the shape and the position of the surface as well as the temperature of the surface and the surroundings. It is independent of the nature of the surface.

The radiation and convection losses from horizontal and vertical plane surfaces have been determined by Langmuir[1] for various ma-

1. Trans. of Am. Electro-Chem. Soc., Vol. 22, p. 299 (1913).

terials. Fig. 9 shows the convection and radiation losses for vertical plane surfaces for temperatures up to 250°C. (482°F.), the highest temperature used in cooking. Fig. 10 shows the convection losses for vertical and horizontal surfaces as given by Langmuir.

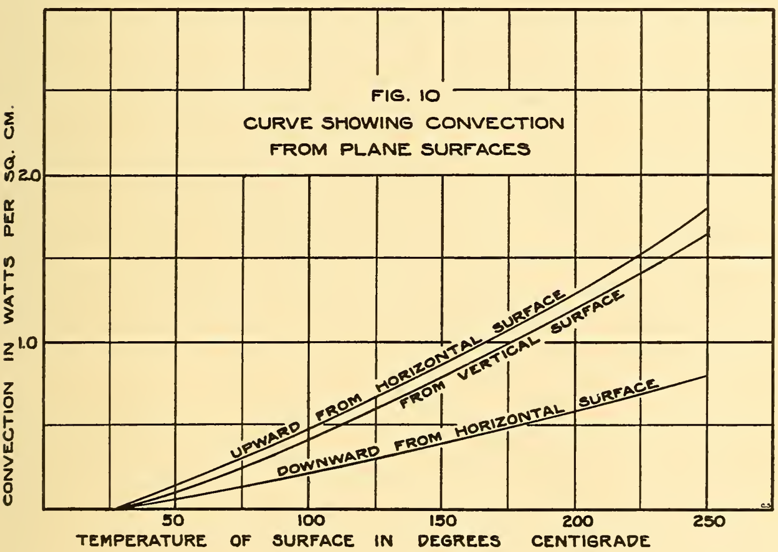
As shown by the curves the radiation loss from a black body constitutes a large part of the total loss, while the radiation from a polished silver surface forms but a small part of the total loss. For all other surfaces the radiation loss lies between that of a silver surface and a black surface; the convection loss being the same for all surfaces.




There are two ways in which the heat losses of an electric oven may be reduced. Consider an oven of given inside dimensions built on the plan of the ordinary gas oven, with a black outside surface and no heat insulation. The temperature of the outside surface will be within a few degrees of the temperature of the oven. A large amount of energy will be required to maintain a cooking temperature inside the oven. Since the convection and radiation losses depend on the temperature of the outside surface, the losses will be greatly reduced if this temperature can be decreased. If the inner and outer surfaces of the oven are separated a few inches and the intervening space filled with some poor conductor of heat such as mineral wool, kieselguhr, or diatomaceous earth, there will be a large drop in temperature between

the inner and outer surfaces, because the heat will be conducted away very slowly from the hot interior.

Suppose that enough heat insulation were introduced to reduce the outside temperature from 200°C. (392°F.) to 110°C. (230°F.), the watts lost per square centimeter of outside surface would be reduced from 0.37 to 0.12 as shown by the curves of Fig. 9. Stated in another way, the energy required to maintain the inside temperature of the oven at its former value would be reduced from 1000 watts to 325 watts for the same amount of outside surface. For the same inside dimensions, however, the area of the outside will be greater because of the




added insulation, hence the reduction in energy will not be quite in the proportion indicated.

Another method of reducing the heat losses would be to silver plate the outside surface of the oven. The heat loss would then be decreased from 0.37 watts per sq. cm. to 0.13, or the energy required to maintain the same inside oven temperature would be reduced from 1000 watts to 350 watts. By a combination of the two methods the input of the oven for the required internal temperature would be reduced from 1000 watts to 165 watts.

To silverplate the outside surface of an electric oven would be too expensive to be practical, but there are cheaper surfaces which radiate a very small amount of energy compared to the ordinary black oven. A white enameled surface, for instance, would be much more

efficient than the black surface. A place in which nickel plating could be used to good advantage would be around the edge of the oven door. Because of the good heat conductivity of the metal which connects the inner and outer surfaces of the oven around the door, the outside temperature of the oven is considerably higher around the edges of the door than elsewhere on the outside. If the nickel plating now used on the legs and corners of the stoves were put around the edge of the door, it would help to decrease the losses and the cost of the oven would be no greater.

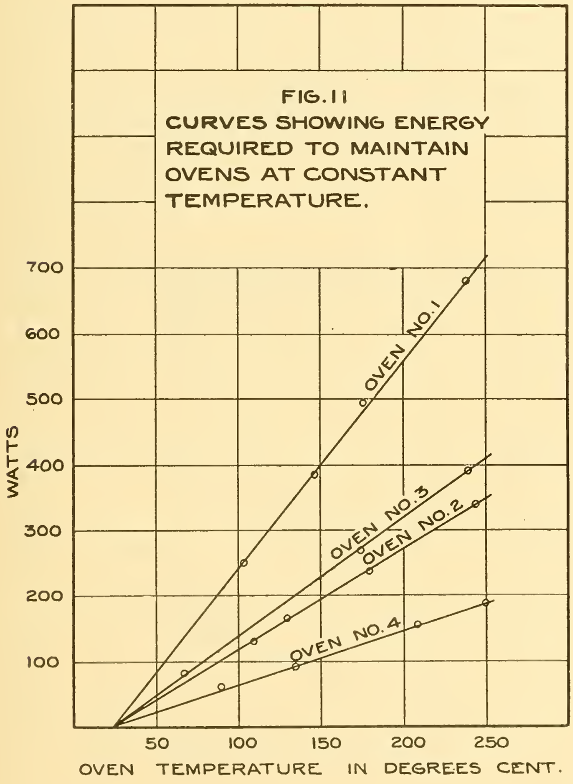
The heat losses from an electric oven can be easily determined by measuring the energy input and the temperature in the oven after equilibrium conditions are established. The heat losses for the ovens tested were obtained in the following manner: A thermo-couple inside the oven was connected to a recording galvanometer. A given amount of energy was turned on so that the temperature of the oven increased until finally the heat lost equaled the energy measured by the wattmeter. The tests were continued until the oven temperature had remained constant for at least two hours. This was repeated for other values of energy input and curves were plotted between oven temperature and watts input as shown in Fig. 11. It will be noticed that the curves obtained are straight lines, all cutting the temperature axis at room temperature. Altho very exact measurements might show a slight upward tendency at higher temperatures, the present results with a maximum error of two per cent are sufficient for practical use.

Since the character of the surface and the outside area will remain constant for a particular oven, the above curves showing the relation between the oven temperature and the energy lost by radiation and convection should be similar to the curves given by Langmuir (Fig. 9). The apparent discrepancy can be accounted for in that the greatest outside temperature of the ovens tested was only 80°C. (176°F.) and below that temperature Langmuir's curves do not depart perceptibly from a straight line.

As will be shown later, the temperature energy curves of Fig. 11 are very useful in comparing the economy of various ovens for the cooking of any given article of food. Since one point of the curve will be zero energy at room temperature, only one determination is necessary to plot the curve for any particular oven. For a given room temperature measure the watts input and the temperature of the oven after it has become constant and plot this point on the diagram. Connect this point and a point on the temperature axis at room temperature with a straight line, and the heat lost from the oven at any given oven temperature may be directly taken from the diagram. These results indicate the energy lost thru the insulation and the metal around the edge of the door. To separate these items the energy

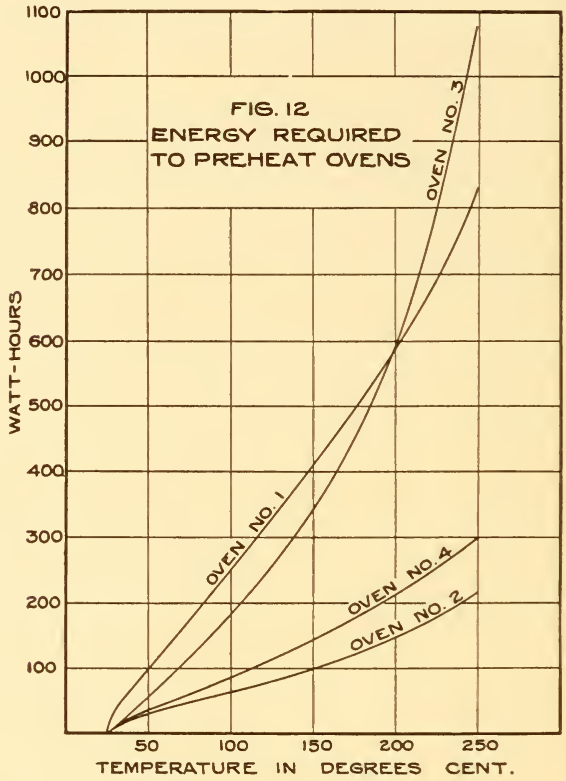
conducted thru the insulation can be directly calculated and subtracted from the total lost energy.

**Preheating Losses.** The heat losses of an electric oven may be resolved into those occurring before and those occurring after the food has been inserted in the oven. In many kinds of cooking, such as baking biscuits and cake, the food must be placed in a hot oven as soon as it is prepared. Since for domestic purposes an oven is never used con-




tinuously, it cools off in the interval during which it is idle. Before it can be again used the inside of the oven and the contained air must be heated up to a cooking temperature. This operation is called preheating. The amount of energy required to preheat an oven to the desired temperature depends upon the insulation of the oven, the dimensions, the thermal capacity of the inside, and the size of the heating coils. The amount of energy required to preheat the ovens tested was

obtained by taking simultaneous readings of the thermometer and the watt-hour meter. Fig. 12 shows the results obtained. It will be noticed that altho oven No. 4 was better insulated than Oven No. 2 it required more energy for the preheating. This was probably due to the greater heat capacity of the inside lining and the throat. The effect of too small a heating coil is shown by the curve for oven No. 3. For high temperatures the energy required for preheating this oven is alto-




gether too large for the size of the oven. The fact that the heating coil is below the bottom of the oven also caused the oven to heat more slowly, the time required for it to reach the higher cooking temperatures being 2.5 hours for 250°C. (482°F.). In order that the energy required for preheating may be as small as possible the inner parts of the oven should have the least practical heat capacity and the heating coils should be large enough to bring the oven to the desired tem-

perature in a fairly short time. If the time required for the oven to reach the cooking temperature is excessive, not only is there a delay in the cooking operation but a larger amount of the energy is lost into the room by radiation and convection during the time of preheating.

**Heat Loss When Oven Door Is Opened.** In preparing food which cannot be placed in a cold oven and gradually heated, there is a loss of heat when the oven door is opened. The amount of this loss and the

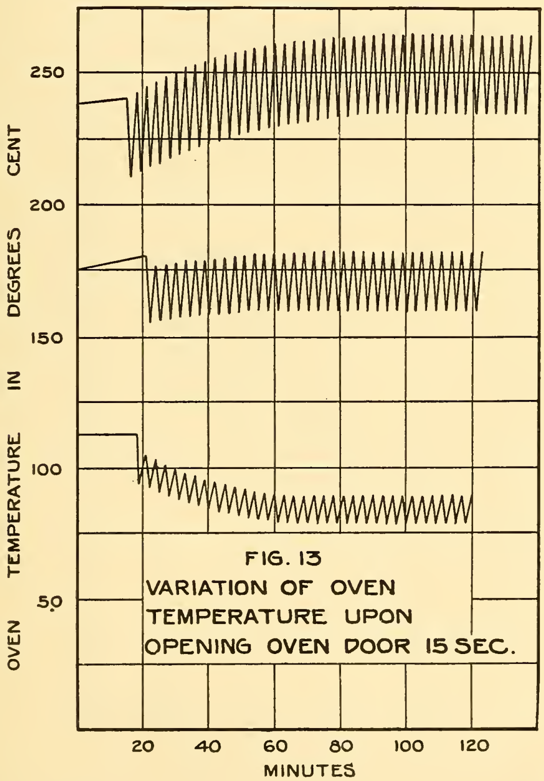
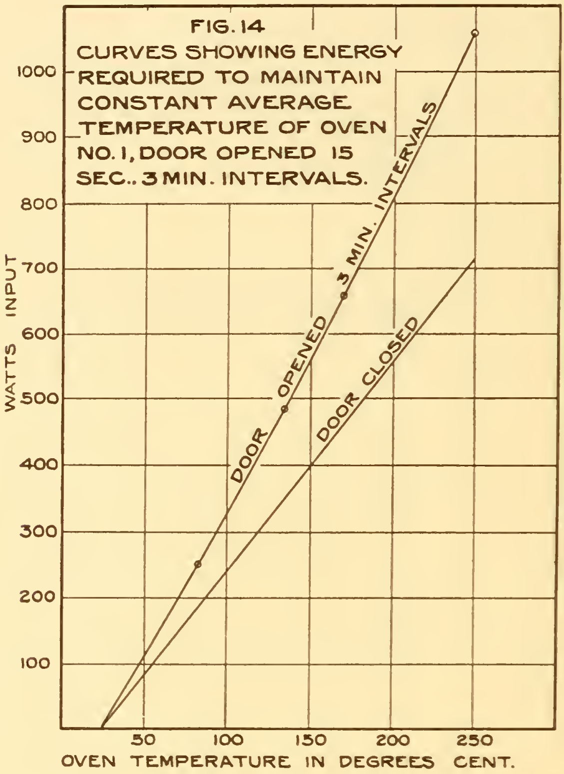



FIG. 13
VARIATION OF OVEN TEMPERATURE UPON OPENING OVEN DOOR 15 SEC.

fall of temperature in the oven were determined for oven No. 1 as follows: The energy input was measured by means of a wattmeter and was kept constant for each test. The temperature of the oven was obtained by means of the thermo-couple and recording galvanometer. The variation of the temperature of the oven when the door was opened for 15 seconds at three-minute intervals is shown in Fig. 13. The average temperature gradually changes and finally reaches a constant

value. A curve plotted for these average temperatures and the energy input is shown in Fig. 14. The difference between the ordinates of this curve and the similar curve obtained with the door closed evidently represents the energy lost by opening the door. From these values the energy lost each time the door is opened is readily calculated. Fig. 15 shows the watt-hours lost each time the door of oven



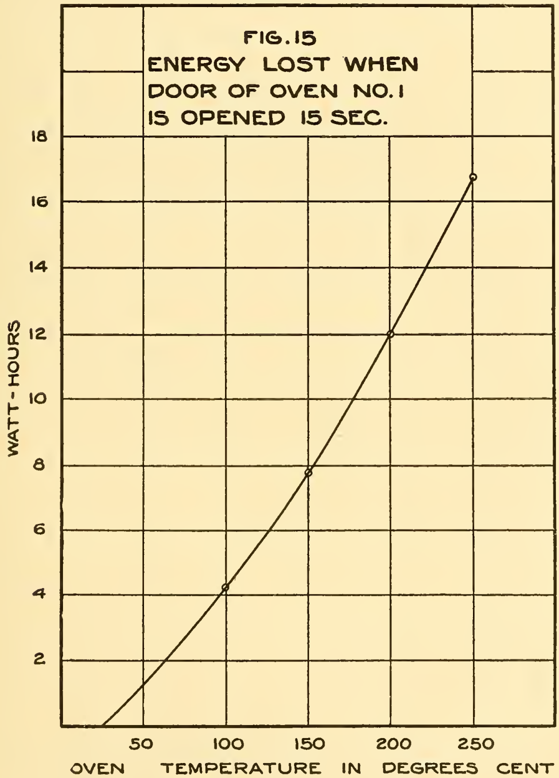

No. 1 is opened for 15 seconds. Fig. 16 shows the fall in temperature of the oven when the door is opened at different oven temperatures.

**Efficiency.** Of the energy input of an electric oven only the part which is absorbed by the food is used to advantage. The remainder goes to supply losses, such as radiation, convection, preheating, opening the oven door, and heating the utensil containing the food.

The ratio of the energy utilized in a piece of apparatus in doing useful work to the total energy input is said to be the efficiency of

that apparatus. Using this meaning, the efficiency of cooking apparatus is the ratio of the energy absorbed by the food to the total energy input of the fuel whether in the form of coal, gas, or electricity.

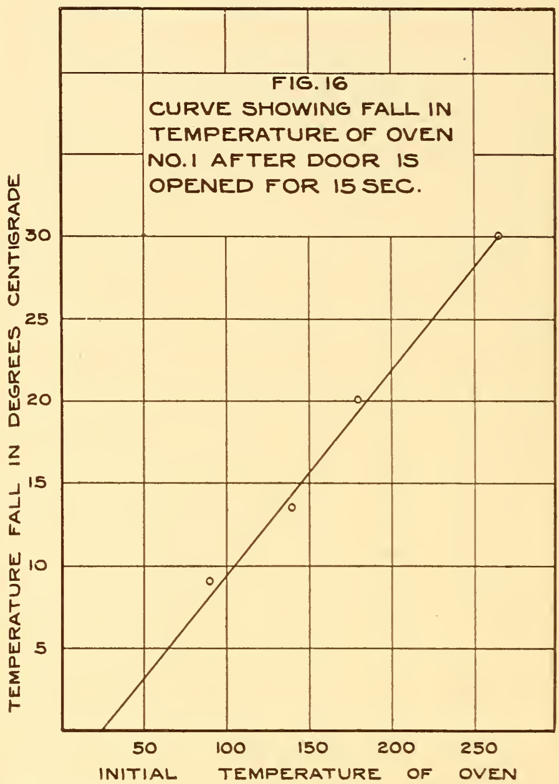
To get a useful expression for the efficiency of a cooking device is not as simple a problem as it may seem. Some investigators have adopted the method used to determine the efficiency of a steam boiler and firebox. They have heated a quantity of water, calculated the




number of heat units absorbed by the water, and taken as the efficiency of the stove or oven the ratio of the heat units absorbed by the water to the heat units supplied by the fuel. This does not take into account the fundamental difference in the purpose of the cooking apparatus and the steam boiler. The purpose of the steam boiler is to convey as many heat units from the fuel to the steam as may be possible. That is, likewise, the purpose in heating water for domestic uses, but it is not the object in view when cooking food.

As explained in a previous paragraph the object in cooking food is to improve its flavor or to increase its digestibility or both. These two factors are the criteria of a well-cooked food. Very often food which has absorbed the greatest number of heat units is the most badly cooked, and the method of cooking which utilizes the largest part of the energy input may give the poorest results.

As an example of why the steam boiler method of determining the efficiency of a cooking device is inadequate, let us suppose that a




cereal is to be cooked for two hours at 90°C. (194°F.). Only such an amount of water is added as will be absorbed by the cereal during the cooking. It is placed in a well-insulated oven, heated rapidly from 20° to 90°C. (68° to 194°F.), and then kept at that temperature for two hours by supplying just enough energy to make up for radiation losses. During the first part of the process energy will be absorbed by the food as it is heated from the room temperature to the

cooking temperature. The efficiency will lie somewhere between 20 per cent and 70 per cent depending on the characteristics of the oven, its initial temperature and the size and shape of the vessel used. During the last part of the cooking process very little energy will be used by the heating coil but practically no energy will be absorbed by the food, so that the efficiency will be zero.

Another oven requiring less energy for preheating and not being so well insulated would show a better efficiency during the first fifteen minutes when the food is being heated up, but during the last two hours would require more energy than the first oven to make up for the greater radiation losses. The total energy supplied might be greater for the second oven and yet the efficiency as calculated from the heating up part of the cooking process, or as determined by heating a known quantity of water, would be less.

Evidently, the final consideration in comparing the efficiency of two ovens is this,—which one will cook a given article of food in the best manner with the expenditure of the least amount of fuel? This suggests another method of specifying the operating efficiencies of cooking apparatus: to determine the amount of energy required to cook a standard article of food under standard conditions, specifying the quality of the food, the quantity, and the time and temperature of cooking. This method might prove satisfactory if the standard conditions could be determined so as to be reliable and be typical of average cooking processes. There would be a difficulty, however, in assuming any one article of food as a standard. The conditions of cooking vary to such an extent that a particular oven might be more economical for cooking one kind of food and less so for another kind. For instance, biscuits require a short time of cooking at a high temperature, ten to fifteen minutes at 200° to 220°C. (392° to 428°F.) while cereals and vegetables are best cooked for several hours at a temperature somewhat below boiling.

Another method of indicating the efficiency of electric ovens would be to specify the energy required to supply the losses. The loss due to opening the oven door will be practically the same for all ovens of the same size so that the principal losses will be those due to radiation, convection and preheating. Evidently, when a particular article of food is cooked under the same conditions of time and temperature in various ovens, the part of the energy input absorbed by the food will be practically the same while the part of the energy input not absorbed by the food, or the losses, will depend upon the characteristics of the oven. If the energy required to heat various ovens to any given temperature and the energy required to maintain the oven temperatures at the desired value are known, then the cost of operation of any of the ovens can easily be determined for any kind of cooking; providing, of course, that the time and temperature used for that cooking are known.

For the purpose of comparison with the results of other investigators the apparent efficiency of three electric ovens and a gas oven were determined by heating a known quantity of water. Four thousand grams of water were used in each test. The water was placed in an aluminum dish weighing 451 grams. This dish was chosen as it was the one used in some meat tests to be described later. The dish was used without a cover. The water was weighed carefully before and after each test. The temperature of the water was read just before it was placed in the oven and just after it was removed. The energy used in evaporation and the energy absorbed by the dish were included in the total energy absorbed. One set of tests was made by placing the water in the oven when the temperature of the oven was the same as that of the room and then turning the heating units on full. Another set of tests was made by placing the water in the oven when the temperature of the oven was 150°C. (302°F.) turning the heat on full until the temperature had returned to that value and then keeping the oven temperature constant for the remainder of the test. Tests were also made with the heating units on top of oven No. 1 and the top burners of the gas stove. The results of the tests are given in Table II.

The high efficiency of the top heating coils is due to the good heat connection between the heating units and the dish of water. On top of the stove there is approximately one-tenth of an inch space between the red hot coils and the bottom of the dish while in the oven the coils and the dish are separated several inches with a baffle between. Because of the poor heat connection between the coils of the oven and the dish the heat is conducted very slowly from the coils to the water.

The results of the tests indicate that water could not be heated as efficiently by placing it in the oven as by heating it on top of the stove. It does not follow, however, that all cooking can be done more economically on top of the stove than in the oven. The contrary may be true in many cases; for instance, it would be cheaper to prepare a pot-roast in oven No. 2 or No. 4 than it would be to prepare it on top of the stove on the heating coil tested. This is because the purpose of cooking the pot-roast is not to put the greatest amount of heat into it with the minimum cost, but the purpose is to keep the roast at a temperature of 80°C. (176°F.) for three or four hours until it is satisfactorily cooked. Articles of food like vegetables or a pot-roast which are prepared in water could be cooked still more economically by removing the baffle from the oven and placing the dish directly on the heating element. Advantage is then obtained of the good heat contact between the heating coil and the dish of food and the smaller radiation losses of the oven. The best results for this kind of cooking in which there is enough water to prevent scorching would be obtained in an insulated oven but little larger than the dish containing the food.

Table II.

Temperature of ovens at beginning of test 25° C. (77° F.).

| Apparatus | Calories absorbed | Energy used | Calories input | Efficiency percent |
|---|---|---|---|---|
| No. 1. oven | 60.4 | 571 watt-hr. | 492 | 12.3 |
| No. 2 oven | 138.9 | 452 watt-hr. | 389 | 35.7 |
| No. 4 oven | 205.5 | 525 watt-hr. | 452 | 45.5 |
| Gas oven | 106.6 | 11 cu. ft. | 1940 | 5.5 |

Temperature of ovens thruout test 150° C. (302° F.).

| | | | | |
|---|---|---|---|---|
| No. 1 oven | 71.4 | 316 watt-hr. | 272 | 26.0 |
| No. 2 oven | 109.0 | 281 watt-hr. | 242 | 45.0 |
| No. 4 oven | 108.5 | 198 watt-hr. | 170 | 64.0 |
| Gas oven | 119.0 | 6.2 cu. ft. | 1100 | 10.8 |
| Gas burner | 191.0 | 2.75 cu. ft. | 485 | 39.4 |
| Top burner No. 1 oven | 243.0 | 457 watt-hr. | 393 | 61.8 |

## MEAT COOKERY

Meat may be cooked by any of the methods in common use,—roasting, baking, frying, broiling, stewing, or boiling. Little has been known concerning the scientific principles of cooking meat until recently. Since there has been no uniformity in the practices and processes of cooking, the terms used vary widely in their meaning. Roasting,—which was formerly applied to cooking over red hot coals,—is now used synonymously with baking or cooking in an oven by means of a dry heat. Stewing and boiling have never been clearly defined. Both apply to the cooking of meat when immersed in water. The present tendency in scientific literature is to use the term boiling when meat is cooked in water at any temperature and to specify the exact temperature used. Broiling and frying will not be discussed in this paper, since it is impractical to utilize the advantages of an insulated electric oven for preparing meat by either method.

There is a wide diversity of taste in regard to the proper degree of cooking of a meat roast. Some people prefer that the meat should be heated only enough to slightly change the color of the interior, while others prefer the meat cooked until every trace of the pink color has disappeared. This difference of taste causes a corresponding variation in the meaning of the terms used to describe the degree to which meat shall be cooked. The meat which one would call rare is, to another, medium rare, and, at times, meat that is actually raw is served as rare.

In this paper the terms rare, medium rare, and well-done are used to indicate the same degree of cooking as defined by Miss E. C. Sprague.[1] The definitions are as follows:

"**Rare or Under-done Meat.** In the center of a rare roast the dull bluish-red characteristic of the raw meat has changed into the bright rose-red of the rare meat. This shades into a lighter pink toward the outer portions and changes into a dark gray in the layer immediately underlying the outer browned crust. The ideal standard for rare meat requires that the larger portion of the roast shall have been heated only enough to effect this first change to rose-red, so that the outer brown crust and the intermediate gray layer shall be as thin as possible. Under these conditions there will be a liberal amount of bright red juice.

"**Well-done Meat.** If the cooking is continued for a sufficient length of time, instead of being distended the meat shrinks noticeably. The whole interior is found to have become brownish-gray in color and the juice is scanty and either colorless or slightly yellow. Meat cooked to this degree is said to be well-done.

"**Medium Rare Meat.** A condition between these two extremes is indicated by the term medium rare. In this case sufficient heat has been applied to change the color of the center to a light pink. The gray layer underlying the crust has, therefore, extended considerably toward the center. The free juice is smaller in quantity and lighter in color than in the rare meat."

The experiments of Grindley and Sprague have demonstrated that beef can be satisfactorily roasted at an oven temperature anywhere between 100° and 200°C. (212° and 392°F.). A beef roast prepared at any temperature within this interval was found to be well browned and attractive looking. No difference was discernible in the tenderness of duplicate roasts cooked at the extremes of temperature. In their opinion the flavor and juiciness of the meat was slightly better at the lower temperatures, whereas at the higher temperature the drippings were better flavored and larger in quantity.

Since a roast of beef can be properly prepared at any temperature between 100° and 200°C. (212° and 392°F.) the most satisfactory temperature within this interval can be determined only by the consideration of other factors, of which the time of cooking and the cost of cooking are the most important. In order to determine this most economical temperature for roasting a rolled rib roast, a series of experiments were performed.

Twenty-two roasts consisting of the third and fourth standing rib cuts, as near alike in size and quality as possible, were obtained from a local market. The meat was freed from bone, tightly rolled, and

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1. University Studies, Univ. of Ill., Vol. 2, No. 4, p. 4.

secured with wooden skewers. Samples were roasted at 100°, 120,° 140°, 160°, and 180°C. (212°, 248°, 284°, 320° and 356°F.) The time required for the cooking and the amount of energy used at each temperature was measured, from which the most economical temperature for cooking a rolled roast was determined.

In order to get uniform results in the degree of cooking of the meat it was necessary to decide on a rather exact method of determining when the meat was sufficiently cooked. As mentioned before, the aim in cooking meat is not to increase its digestibility but to improve its flavor and appearance. This is accomplished by decomposing the red coloring matter called oxyhaemoglobin, which removes the raw appearance of the meat. The inside of the roast should be heated sufficiently to accomplish this without overcoagulating the proteids or removing from the meat those substances which tend to become soluble or volatile upon the application of heat.

Milroy's experiments [1] show that approximately 50 per cent of the protein of fresh beef was coagulated at 50°C. (122°F.), 70 per cent at 60°C. (140°F.), 90 per cent at 70°C. (158°F.) and 100 per cent at 80°C. (176°F.). At about 75°C. (167°F.) the oxyhaemoglobin undergoes a decomposition which probably marks the disappearance of the last trace of red in the meat. These results would indicate that the inside of the meat ought to reach a temperature between 50° and 80°C. (122° and 176°F.) to be properly cooked, the exact temperature depending upon the degree of cooking which people prefer.

Grindley and Sprague [2] found that if the inner temperature of a roast is between 55° and 65°C. (131° and 149°F.) the meat will be rare, if it is between 65° and 70°C. (149° and 158°F.) it will be medium rare, and if between 70° and 80°C. (158° and 176°F.) it will be well done. In order to secure as much uniformity as possible in the results, a definite temperature rather than a range of temperature was taken as an indication when the meat was sufficiently cooked. Fifty-five degrees C. (131°F.) was used for rare, 65°C. (149°F.) for medium rare, and 75°C. (167°F.) for well done which conforms to the usage of other experimenters. It was not always possible, however, to obtain the exact inner temperature to a degree, because if the roast is taken out of the oven when the inner portion of the meat is at some particular temperature, this temperature will first increase several degrees before it begins to decrease. This increase of temperature after the roast is removed from the oven depends upon the temperature of the oven in which the meat is cooked, being greater for a high oven temperature. The following temperatures of the roasts when removed from the oven were found to give the desired results:

1. Archiv. f. Hyg., 1895, XXV., p. 154.
2. Univ. of Ill. Bul., Vol. II, p. 290.

Table III.

| Oven Temperature. Degrees | | Inner temperature of the meat when removed from the oven. Degrees | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rare | | Medium Rare | | Well Done | |
| Cent. | Fahr. | Cent. | Fahr. | Cent. | Fahr. | Cent. | Fahr. |
| 100 | 212 | 53 | 127.4 | 63 | 145.4 | 75 | 167.0 |
| 120 | 248 | 51 | 123.8 | 61 | 141.8 | 73 | 163.4 |
| 140 | 284 | 49 | 120.2 | 59 | 138.2 | 72 | 161.6 |
| 160 | 320 | 46 | 114.8 | 57 | 134.6 | 71 | 159.8 |
| 180 | 356 | 43 | 109.4 | 55 | 131.0 | 70 | 158.0 |
| | | Highest inner temperature of the roast after removing from the oven. | | | | | |
| | | 55 | 131.0 | 65 | 149.0 | 75 | 167.0 |

A copper-constantan thermo-couple, as described in a preceding chapter, was used to measure the temperature inside the roasts. The thermo-couple was connected to the recording galvanometer which gave a continuous record of the temperature at the center of the roast. Fig. 17 shows some of these curves reproduced on rectangular co-ordinates. Altho these curves do not have a direct bearing on the problem in hand, they are given here as they may be of some interest in other cooking investigations.

The authorities on meat cooking recommend that a roast be cooked for the first ten or fifteen minutes at an oven temperature of 250°C. (482°F.) so as to sear the outside of the meat. The theory is that the coagulation of the outer surface of the meat will act as a seal to keep in the meat juices. A consideration of the heating curves of the electric ovens, discussed in the first part of this paper, shows that to heat an oven up to 250°C. and keep it there for fifteen minutes will increase the cost of electricity for roasting the meat about 50 per cent. In order to reduce this extra cost of energy another method was tried which proved very successful. Instead of searing the meat in an oven at a high temperature it was seared on top of the stove or rather by placing it in an aluminum dish over an 880-watt heating coil. The current was turned on for three minutes to get the dish quite hot. The meat was then placed in the hot dish and seared for ten minutes, being turned frequently so as to sear all sides.

After searing, an incision was made in the roast with a sharp narrow-bladed knife, and the thermo-couple was inserted as near as possible in the center of the large muscle of the roast. The roast was then placed in the oven at the required temperature. Placing the roast in the oven lowered the temperature from 10° to 20°C. (18° to 36°F.). The full current of the oven was then turned on and in two to five minutes the temperature of the oven had again reached the

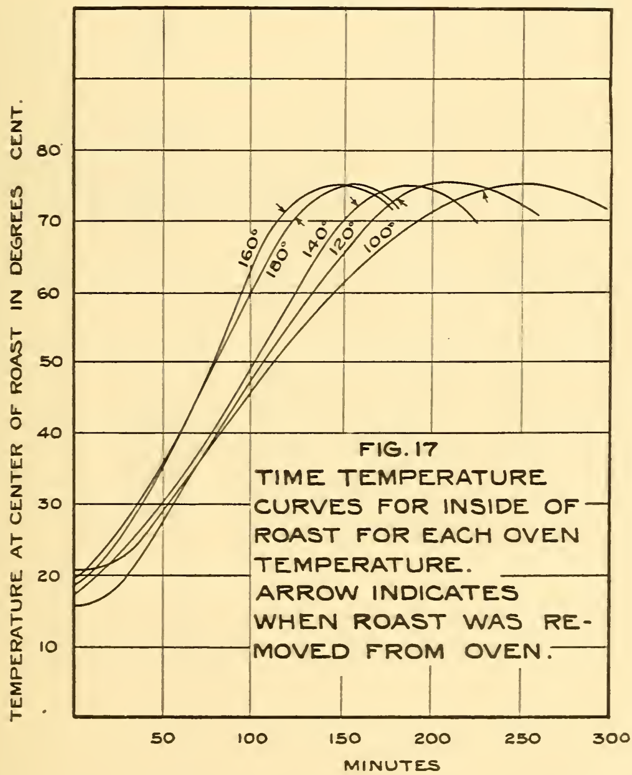


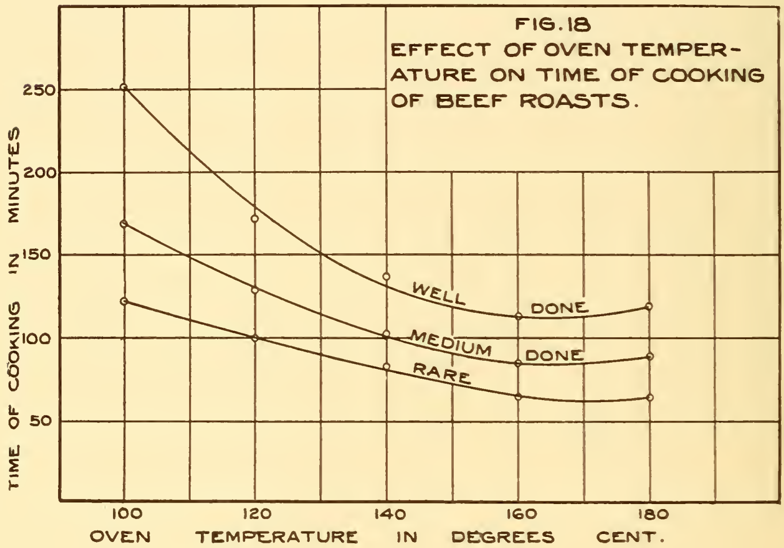

FIG. 17
TIME TEMPERATURE CURVES FOR INSIDE OF ROAST FOR EACH OVEN TEMPERATURE. ARROW INDICATES WHEN ROAST WAS REMOVED FROM OVEN.

required value. During the remainder of the test the current in the oven was varied by means of a rheostat so that the temperature remained constant within 2°C. (3.6°F.) of the desired value.

When the temperature inside the roast indicated the meat to be cooked rare, the time and watt-hour readings were recorded. This was also done for medium rare and well done. As soon as the inside temperature indicated the meat to be well done, the roast was taken

out of the oven and left on a shelf in front of the oven, the leads of the thermo-couple being long enough so that it could still be left inside the meat. The meat was allowed to stand until after the temperature had reached its maximum value. It was then weighed and put on ice until the next day when it was cut into and examined.

Table IV. gives the time of cooking of the roasts for rare, medium rare, and well done. The average values lie close to smooth curves as




shown in Fig. 18. It will be noticed that at an oven temperature of 160°C. (320°F.) the roasts are cooked in a shorter length of time than at 180°C. (356°F.). This is probably due to the fact that the slightly charred surface of the meat is a poorer conductor of heat. For the well-done roasts the time of cooking increases rather rapidly as the temperature decreases. This is not a disadvantage, however, if the proper temperature can be obtained automatically without the attention of the cook.

Table IV.

| Temp. of oven | | Time of cooking of meat roasts in minutes | | | |
|---|---|---|---|---|---|
| Cent. | Fahr. | Rare | | | Average |
| 100 | 212 | 121 | 122 | 120 | 121 |
| 120 | 248 | 107 | 89 | 97 | 98 |
| 140 | 284 | 99 | 76 | 71 | 82 |
| 160 | 320 | 53 | 71 | 67 | 64 |
| 180 | 356 | 80 | 58 | 53 | 63 |
| | | Medium Rare | | | |
| 100 | 212 | 162 | 176 | 170 | 169 |
| 120 | 248 | 139 | 114 | 124 | 126 |
| 140 | 284 | 111 | 89 | 106 | 102 |
| 160 | 320 | 75 | 91 | 86 | 84 |
| 180 | 356 | 105 | 82 | 75 | 88 |
| | | Well Done | | | |
| 100 | 212 | 241 | 260 | 248 | 250 |
| 120 | 248 | 177 | 165 | 172 | 171 |
| 140 | 284 | 151 | 124 | 132 | 136 |
| 160 | 320 | 164 | 120 | 113 | 112 |
| 180 | 356 | 135 | 105 | 113 | 118 |

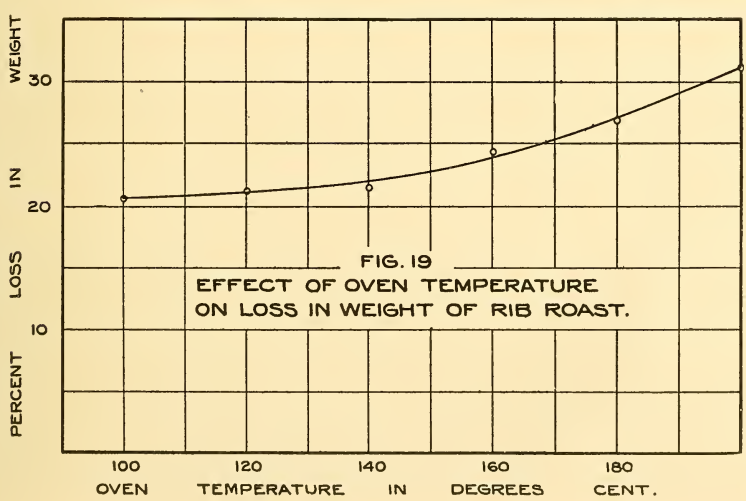



FIG. 19
EFFECT OF OVEN TEMPERATURE ON LOSS IN WEIGHT OF RIB ROAST.

Table V gives the weights of the roasts before and after cooking and the per cent loss in weight due to the cooking. The average values of the per cent loss in weight of the roasts in cooking are plotted in Fig. 19. It will be noticed that the per cent loss in weight of the roasts increases with the temperature. The curve shows that in cooking a well-done roast so far as losses are concerned, meat is best when cooked between 100° and 120°C. (212° and 248°F.) or possibly lower.

Table V.

| Temp. of oven | | Weight before cooking Grams | Weight after cooking Grams | Loss in weight | Per cent loss in weight | Average per cent loss |
|---|---|---|---|---|---|---|
| Cent. | Fahr. | | | | | |
| 100 | 212 | 1904 | 1502 | 402 | 21.1 | |
| | | 1600 | 1288 | 312 | 19.5 | |
| | | 1760 | 1392 | 368 | 20.9 | 20.5 |
| 120 | 248 | 1580 | 1270 | 310 | 19.6 | |
| | | 1782 | 1380 | 402 | 22.6 | |
| | | 1824 | 1434 | 390 | 21.4 | 21.2 |
| 140 | 284 | 1700 | 1352 | 348 | 20.5 | |
| | | 1900 | 1492 | 408 | 21.5 | |
| | | 1820 | 1414 | 406 | 22.3 | 21.4 |
| 160 | 320 | 1554 | 1160 | 394 | 25.3 | |
| | | 1612 | 1237 | 375 | 23.2 | |
| | | 1566 | 1182 | 384 | 24.5 | 24.3 |
| 180 | 356 | 1628 | 1220 | 408 | 25.1 | |
| | | 1832 | 1335 | 497 | 27.1 | |
| | | 1814 | 1300 | 514 | 28.3 | 26.8 |
| 200 | 392 | 1805 | 1244 | 561 | 31.0 | 31.0 |

As the proper facilities were not available, no attempt was made to analyze the drippings obtained at the various temperatures to determine the proportion of water, protein, and fat. The appearance of the drippings, however, would indicate that there is a larger proportion of fat in the drippings obtained at the high oven temperatures than at the low temperatures.

The other important factor which determines the best roasting temperature is the cost of the electricity used. As an aid to clearness in determining the most economical roasting temperature the total

energy used in cooking the meat will be divided into several components and each will be discussed separately.

As mentioned before the roasts were first seared over an open heating coil. This operation required 880 watts for 13 minutes or 190 watt-hr. and was the same for all the roasts.

Part of the total energy was used in heating the oven from room temperature to the temperature required for the cooking. This was done before the roast was put in the oven and is commonly known as preheating. The amount of energy required for this purpose, as shown in a preceding paragraph, depends upon the construction of the oven and the size of the heating coil. The curves of Fig. 12 show the energy required for the ovens tested.

If food is placed in an oven after the oven is heated to a certain temperature, the temperature will decrease, due partly to the heat lost by opening the door and partly to the heat absorbed by the cold utensil and food. To bring the temperature of the oven up to its former value additional energy will have to be supplied. The term afterheating will be used in this paper to distinguish this heating of the oven after food is inserted from the heating of the oven before the food is placed in it.

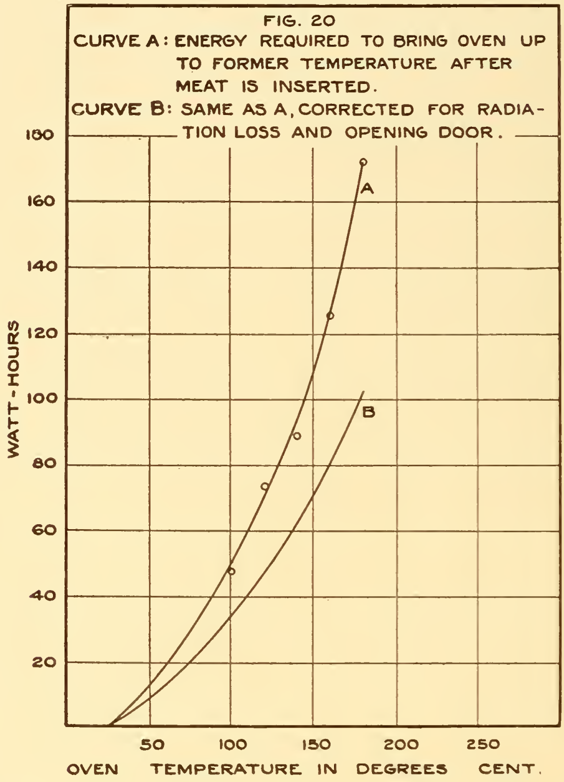
In the meat experiments the energy used in afterheating was determined. As soon as the meat was placed in the oven the current was turned on full until the temperature of the oven had increased to its original value. The reading of the watt-hour meter was then taken. The watt-hours thus determined are given in column 3 of Table VI for the various oven temperatures.

Table VI.

| Oven temperature | | Watt-hours required to bring oven temp. to former value after opening the door. | Watts required to maintain the oven and roast at constant temperature. |
|---|---|---|---|
| Cent. | Fahr. | | |
| 100 | 212 | 44 | 249 |
| 120 | 248 | 67 | 321 |
| 140 | 284 | 75 | 395 |
| 160 | 320 | 114 | 485 |
| 180 | 356 | 156 | 586 |

The variation of this energy with the oven temperature is shown by curve A in Fig. 20. The time required for the oven temperature to attain its former value after the roast was inserted varied from two to five minutes. During this time part of the energy supplied was

lost by conduction thru the insulation and around the throat as explained in a preceding paragraph. As this heat loss thru the walls of the oven is known for a particular temperature, the energy measured by the watt-hour meter (curve A Fig. 20) can be corrected by subtracting the energy lost thru the walls during the time required for the afterheating. Curve B Fig. 20 shows these corrected values. The

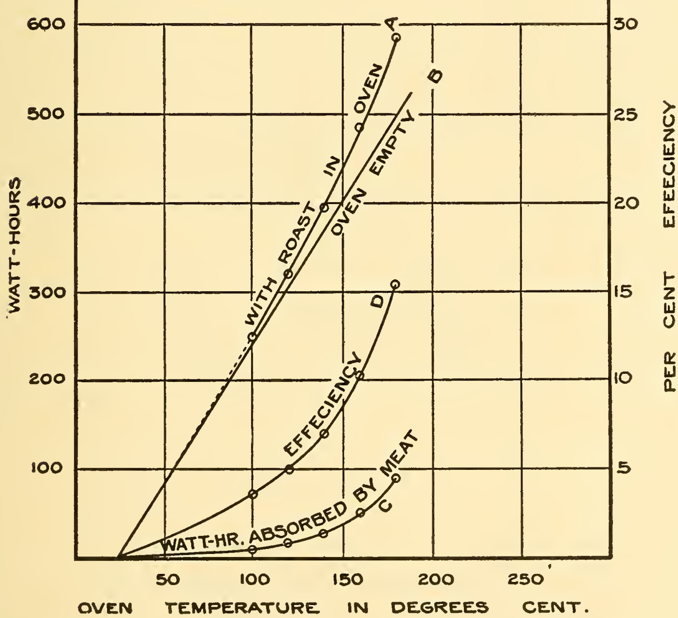



ordinates of this curve are a measure of the energy used in afterheating at the various oven temperatures.

After the temperature of the oven has attained the desired value the energy supplied to maintain this temperature is practically constant. Since the cooking of a roast consists in raising its temperature to 60°C. (140°F.) or above, there is a constant supply of heat energy to the meat. Part of this is used in increasing the internal temperature of the meat and part is used in vaporizing the water and other

volatile matter of the meat. Column 4 of Table VI gives the watts required to maintain the oven and roast at a constant temperature. Curve A Fig. 21 shows these values of watts plotted against oven temperature as abscissas. For the sake of comparison a similar curve for the empty oven is here repeated. The difference between these two curves is the energy absorbed by the meat either in increasing its temperature or vaporizing its moisture.

FIG. 21
ENERGY REQUIRED TO MAINTAIN OVEN AT CONSTANT TEMPERATURE WITH ROAST IN OVEN; AND EMPTY.




Consideration of these curves leads to a method of determining the ratio of the heat units absorbed by the food to the total heat units supplied. Since the ordinates of curve B represent the energy required to maintain the oven at a constant temperature when empty and the ordinates of curve A represent the energy required to maintain the oven at a constant temperature after the roast is placed therein; the difference between the two may be taken as a measure of the

energy actually absorbed by the food. In other words the difference between the ordinates represents the energy output of the oven. Therefore, for any oven temperature the ordinate of curve A minus the ordinate of curve B divided by the ordinate of curve A would equal the efficiency of the oven when roasting beef. Curve D of Fig. 21 gives the values of the efficiency obtained by this method. Even if

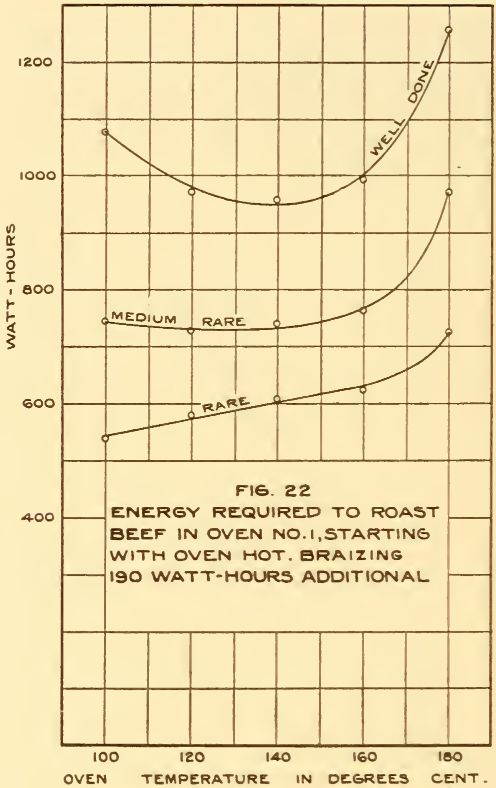
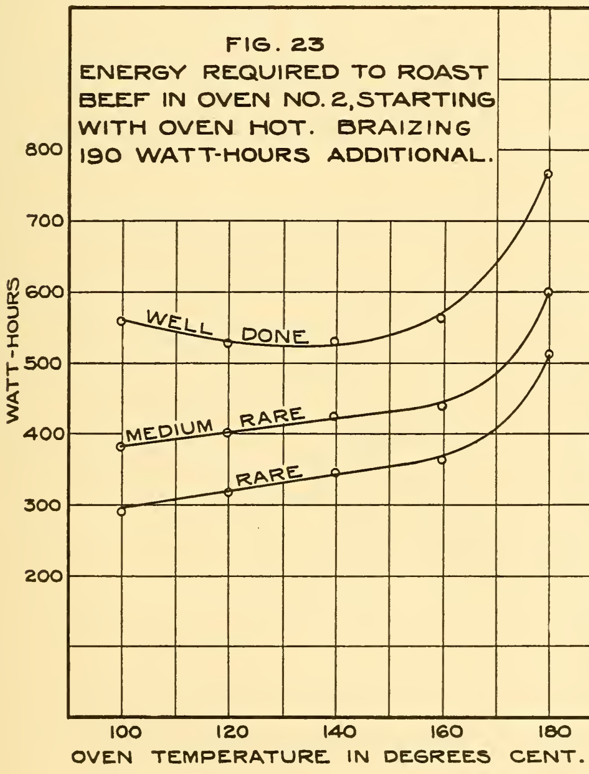



FIG. 22
ENERGY REQUIRED TO ROAST BEEF IN OVEN NO. 1, STARTING WITH OVEN HOT. BRAIZING 190 WATT-HOURS ADDITIONAL

the best accuracy were obtainable by this method it does not tell much about the actual cost of roasting meat. It well emphasizes the fact, which was discussed in a previous paragraph, that the method of measuring the efficiency of a steam boiler is not adaptable to cooking apparatus. According to the curve just obtained, the energy required for roasting beef at 180°C. (356°F.) ought to be less than at lower temperatures. Quite the contrary is true, however. At 180°C. more heat units are absorbed by the meat than at lower temperatures, but

this excess of heat in the meat is detrimental to its quality. The extra amount of heat is used to cause a larger loss in weight of the meat as shown by the curve in Fig. 19. It also chars the outside of the meat, forming a heavy crust which is very indigestible.

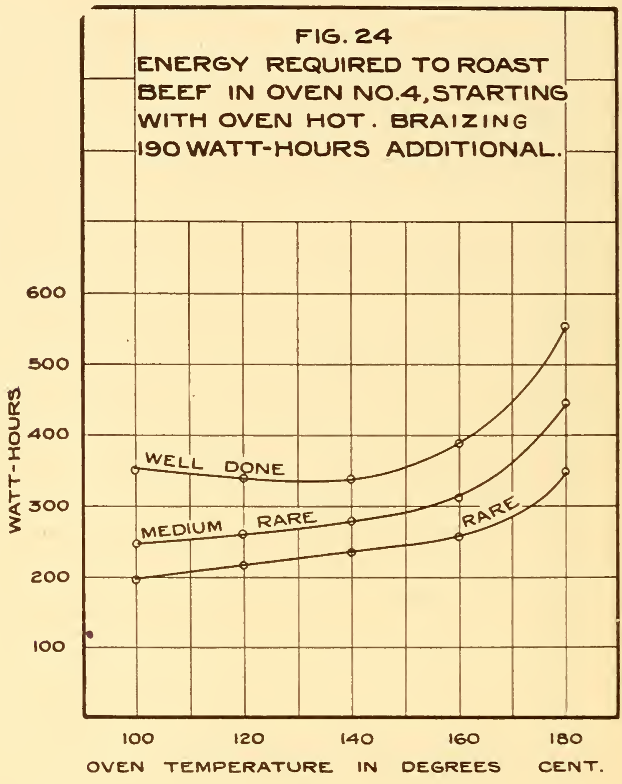
The curves of Figs. 22, 23, and 24 give the energy used in roasting beef in ovens Nos. 1, 2, and 4, starting with the oven at the required temperature. The energy used in braizing (or searing) the roasts is




not included in the ordinates to these curves, since it was the same in all cases, 190 watt-hours. It will be noticed that for rare roasts 100°C. (212°F.) is the most economical temperature in all the ovens, and for medium rare 100°C. is the most economical temperature except for oven No. 1 for which 120°C. to 140°C. (248°F. to 284°F.) is the best. The difference in this case is very slight, however, and within the probable error so that 100°C. could be used economically

even here if desired. For the well-done roasts there is a decided difference in the cost of cooking the meat at the various oven temperatures. For all the ovens the most economical temperature for the well-done roasts lies between 120° and 140°C.

When it is necessary to heat up the oven from room temperature different curves are obtained as shown in Figs. 25, 26, and 27. It




will be noticed that the rare and medium rare curves are much steeper and the difference in cost in favor of 100°C. is greater. For ovens No. 1 and 2 120°C. (248°F.) is the most economical temperature for well-done roasts while for oven No. 4, 100°C. is the best. With the cost of electricity at 5 cents per kilowatt-hour for oven No. 1 the difference between the cost of roasting meat at 100°C. and at 180°C. is 2 cents for rare, 2½ cents for medium rare, and for well-done the difference between 120°C. and 180°C. is 2½ cents. The saving in the

month's bill for the average family would probably amount to about 50 cents. It is well worth considering, however, since by observing these economies electric cooking will be able to compete with the cheaper fuels.

It will be noticed that the energy required for roasting meat in oven No. 1 is considerably greater than in ovens No. 2 and 4. This is due partly to the smaller amount of heat insulation used and partly

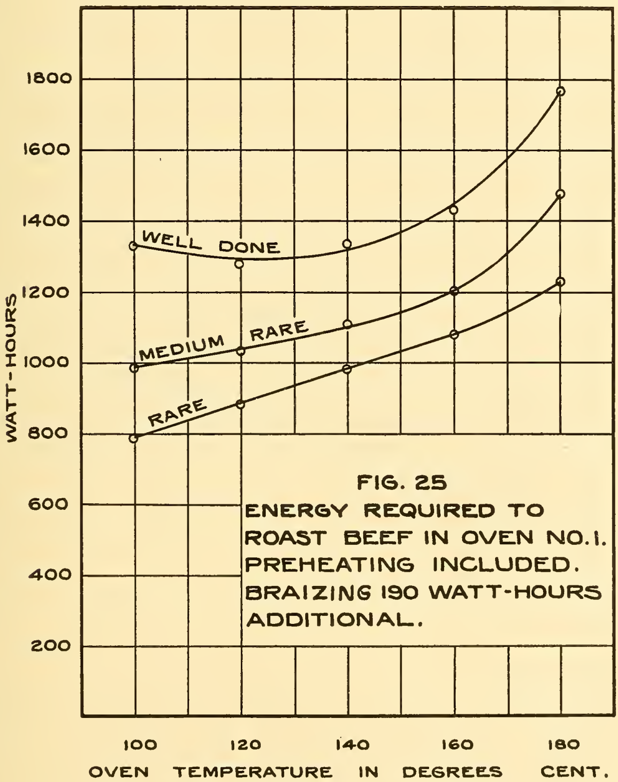


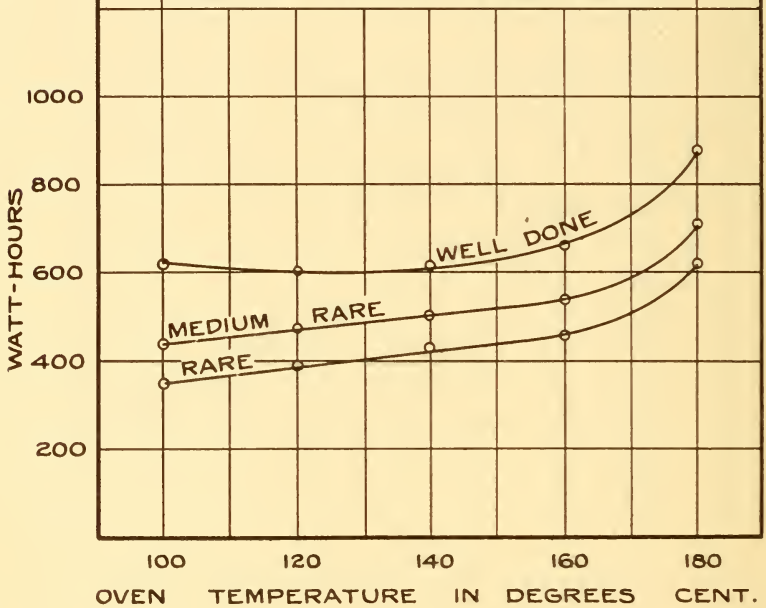

FIG. 25
ENERGY REQUIRED TO ROAST BEEF IN OVEN NO. 1. PREHEATING INCLUDED. BRAIZING 190 WATT-HOURS ADDITIONAL.

to the larger size of the oven. The oven was much larger than was necessary for cooking this size of roast. On this account both the radiation losses and the preheating loss were much greater than in the smaller ovens.

The energy curves just described were obtained in the following manner: The radiation loss was calculated for the required time of cooking. To this was added the loss due to opening the door and the

energy absorbed by the meat as given by the curves of Fig. 20 and 21. The values thus obtained were checked for 100°C. (212°F.) and 160°C. (320°F.) by cooking roasts at these temperatures in ovens No. 2 and 4. Oven No. 3 was tried at 160°C. but the heating element was found inadequate to maintain the required temperature in the oven after the roast was placed therein. The energy curves for this oven were therefore not obtained.

FIG. 26
ENERGY REQUIRED TO ROAST BEEF IN OVEN NO. 2. PRE-HEATING INCLUDED. BRAIZING 190 WATT-HOURS ADDITIONAL.



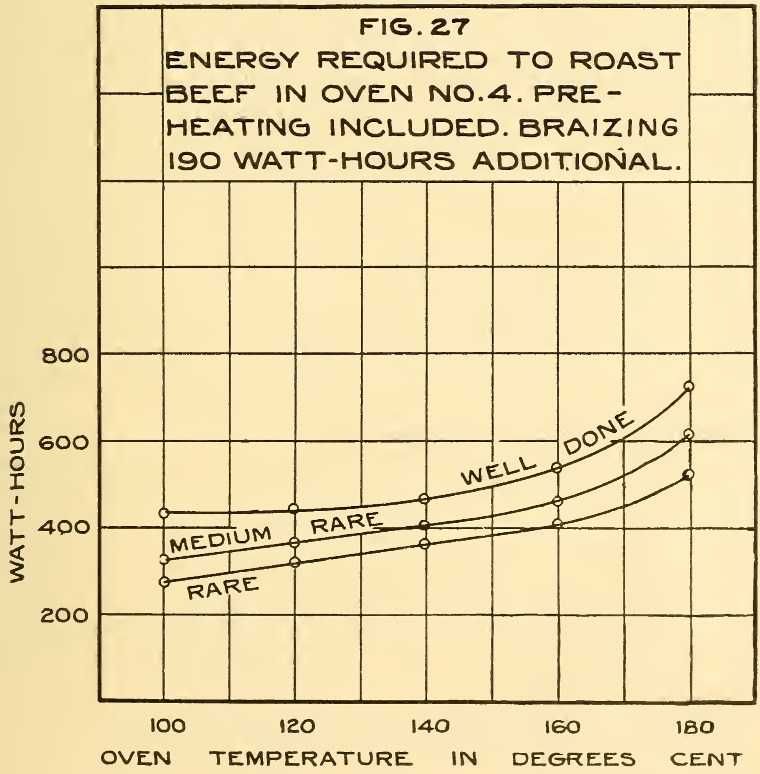

An experiment was tried by braizing the roast in the manner recommended by the cook books. The oven was heated to 250°C. (482°F.) the roast was placed therein, and full current was turned on until the temperature had returned to the desired value. The current was then turned off and the oven allowed to cool down to 100°C. (212°F.) where it was kept constant during the remainder of the experiment. The energy required for preparing the roasts by both methods is given in the following table:

Table VII.

Watt-hours used in preparing roasts by the two methods of searing

| | Searing on top coil | Remainder of test in oven at 100 °C. (212 °F.) | Total | Total when seared in oven | Difference |
|---|---|---|---|---|---|
| Rare........ | 190 | 790 | 880 | 1950 | 1070 |
| Well done.... | 190 | 1325 | 1515 | 2580 | 1065 |

The saving in energy in favor of searing on top of the stove is surprisingly great, making a difference of 5 cents (at five cents per



kw-hr.) in the cost of preparing the roast. This great difference in the energy used by the two methods is due to the fact that when searing the meat in the oven the whole oven had to be heated up to the high temperature of 250°C. (482°F.) resulting in large preheating and radiation losses, while by the other method only the heating element, the dish, and the outside surface of the roast are heated to the high temperature. The losses are consequently greatly reduced.

**Boiling meats.** Electric insulated ovens of the proper construction are particularly adapted to boiling meats or rather cooking in water at the desired temperature. This process requires a long time and a low degree of heat.

The researches of Grindley [1] have disposed of the theory that meat should be first placed in water at the boiling temperature for ten minutes to seal up the outside. He says, "Thoro investigation confirms the conclusion that when meat is cooked in water at from 80° to 85°C. (176° to 185°F.), placing the meat in hot or cold water at the start has little effect on the amount of material found in the broth." The most economical method of boiling by means of electricity is, therefore, to immerse it in water and place it in the oven without preheating. If a small well-insulated oven is used and the dish placed directly on the heating element without a baffle, the meat can be cooked by using only a small amount of electricity.

Experiments on the temperature of coagulation of proteid and the decomposition of oxyhaemoglobin, the red coloring matter of meat, indicate that the probable lowest temperature of cooking meat is in the neighborhood of 75°C. (167°F.). One hundred degrees centigrade, the boiling point of water, will be the highest temperature used and the most economical temperature will be somewhere within this interval.

The increased popularity of the fireless cooker indicates that people are learning that food can be cooked below the boiling temperature and that meat is more tender and appetizing when cooked at 80°C. than at 100°C. as shown by many experiments. Cheap cuts of meat can be used and sometimes made nearly as attractive as the more expensive cuts cooked in the ordinary way.

No experiments were undertaken on cooking meats in water, hence no definite data can be given as to the amount of electricity required for such cooking.

## BAKING EXPERIMENTS

Owing to a lack of definite information on the time and temperature of baking, a series of experiments were undertaken on the baking of biscuit, bread. and sponge cake. The purpose of the experiments

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1. Losses in Cooking Meat, U. S. Dept. of Ag. Bul. No. 141, p. 95.

was to determine the range of temperatures within which each article of food could be satisfactorily baked and the particular temperature within this interval which was the most economical for the ovens tested.

The method used was to determine the minimum time of baking at several oven temperatures. The experiments at a particular temperature were started at what was thought to be the proper time of baking at that temperature. If the condition of the food was well done and well browned the time of baking was reduced. This process was repeated until under-done samples were obtained. The shortest time of baking which gave satisfactory results was taken for that particular temperature. This was repeated for several oven temperatures and curves were plotted between the temperature of oven and the minimum time of baking. Each sample was carefully weighed before and after baking and the per cent loss of weight determined. The per cent loss of weight obtained at the minimum time of baking was then plotted against the oven temperature. Each point obtained on this curve was the mean of three determinations. The experiments were first performed in Oven No. 1 and were then checked in the other ovens.

Because of the short time of cooking and the small amount of food used in each sample it was not found possible, as in the meat experiments, to get accurate measurements of the amount of heat absorbed by the food. Consequently the amount of energy used in baking at the various temperatures in each oven was taken as the sum of the losses.

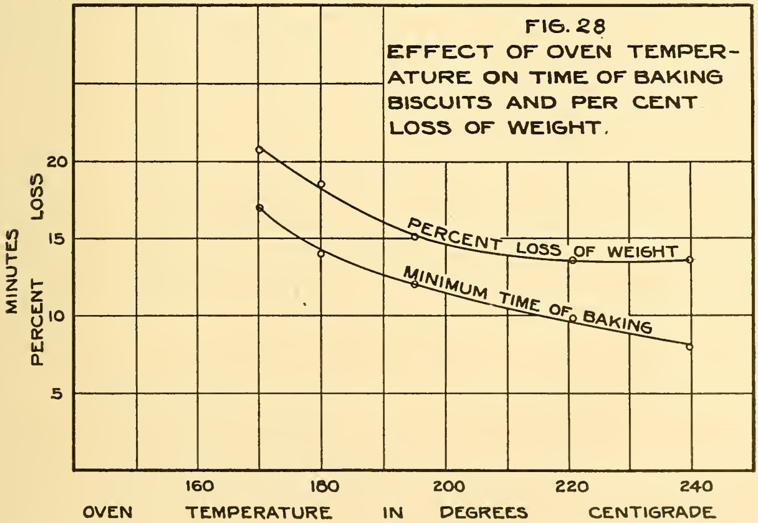

Fig. 28 shows the minimum time of baking and the per cent loss in weight curves for biscuits. Each sample consisted of six biscuits, the total sample weighing approximately 25 grams. They were prepared according to the following recipe:

1 cup of flour,
1 tablespoonful of lard,
½ teaspoonful of salt,
2 teaspoonfuls of baking powder,
enough milk to make a soft dough.

It will be noticed from the curves that the per cent loss of weight begins to increase very rapidly as the temperature decreases below 200°C. (392°F.). This increase in the loss of weight of the biscuits at the low temperatures indicated that the samples dried out to a greater extent due to the increased time of baking. This was very evident in the character of the biscuits prepared at these temperatures. They were dry and hard and had a heavy crust, instead of being crisp and tender. At 200°C. and above there was no difference discernible in the character of the samples. The range of temperature, therefore, for baking biscuits prepared according to the above recipe is from 200° to 240°C. (392° and 464°F.). Table VIII which gives in detail the results of the biscuit experiments will make clear the method used.

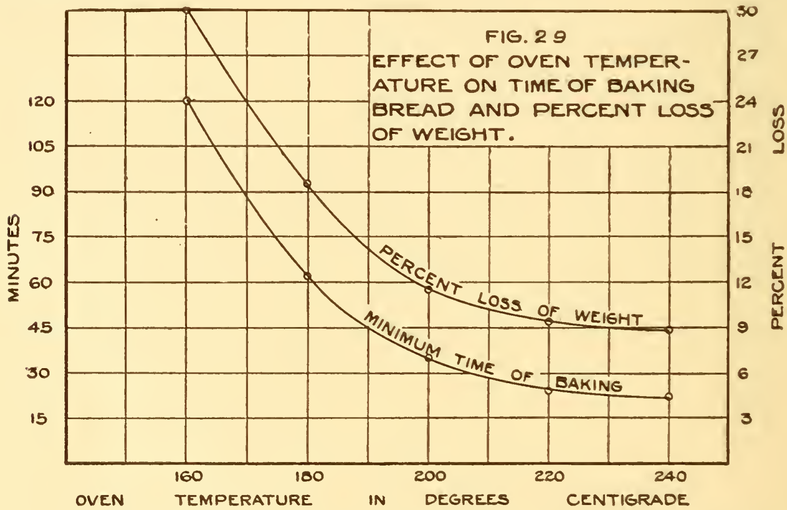


Fig. 29 shows the minimum time of baking and the per cent loss of weight curves for the bread experiments. The loaves averaged 300 grams in weight and were baked in a tin the dimensions of which were 3 inches by 5 inches by 3 inches deep. The bread was prepared according to the following recipe:

**Table VIII—Biscuit Experiments**

| Time of baking | Oven temperature | | Percent loss of weight | Condition of sample |
|---|---|---|---|---|
| | Cent. | Fahr. | | |
| Minutes | | | | |
| 10 | 239.5 | 463.1 | 15.8 | well done, well brown |
| 10 | 239.5 | 463.1 | 15.5 | well done, well brown |
| 10 | 240.0 | 464.0 | 15.9 | well done, well brown |
| 8 | 239.5 | 463.1 | 12.9 | well done, well brown |
| 8 | 239.0 | 462.2 | 14.9 | well done, well brown |
| 8 | 240.0 | 464.0 | 13.0 | well done, well brown |
| 7 | 241.0 | 465.8 | 10.1 | slightly brown, doughy |
| 7 | 240.5 | 464.9 | 10.8 | slightly brown, done |
| 7 | 240.0 | 464.0 | 10.1 | slightly brown, almost done |
| 10 | 220.0 | 428.0 | 13.0 | well done, well brown |
| 10 | 221.0 | 429.8 | 12.9 | well done, well brown |
| 10 | 221.0 | 429.8 | 14.4 | well done, well brown |
| 10 | 220.0 | 428.0 | 14.3 | well done, well brown |
| 9 | 220.0 | 428.0 | 12.9 | not brown, doughy |
| 9 | 221.0 | 429.8 | 12.2 | slightly brown, done |
| 12 | 195.0 | 383.0 | 14.2 | well done, well brown |
| 12 | 194.0 | 381.2 | 15.1 | well done, well brown |
| 12 | 196.0 | 384.8 | 15.9 | well done, well brown |
| 10 | 195.0 | 383.0 | 8.0 | slightly brown, done |
| 10 | 195.0 | 383.0 | 7.2 | slightly brown, almost done |
| 11 | 195.0 | 383.0 | 15.0 | well done, slightly brown |
| 11 | 195.0 | 383.0 | 13.6 | almost done, brown |
| 11 | 195.5 | 383.9 | 14.6 | almost done, slightly brown |
| 14 | 180.0 | 356.0 | 17.8 | well done, well brown |
| 14 | 180.5 | 356.9 | 19.2 | well done, well brown |
| 14 | 180.0 | 356.0 | 18.8 | well done, well brown |
| 13 | 180.0 | 356.0 | 13.0 | slightly brown, almost done |
| 13 | 180.0 | 356.0 | 11.6 | well done, well brown |
| 13 | 180.5 | 356.9 | 14.3 | brown, almost done |
| 15 | 170.0 | 338.0 | 17.0 | almost done, not brown |
| 15 | 170.0 | 338.0 | 16.5 | almost done, not brown |
| 15 | 170.0 | 338.0 | 16.2 | almost done, slightly brown |
| 16 | 170.5 | 338.9 | 10.7 | done, slightly brown |
| 16 | 170.5 | 338.9 | 13.3 | done, slightly brown |
| 16 | 169.5 | 337.1 | 12.7 | almost done, slightly brown |
| 17 | 170.0 | 338.0 | 20.9 | well done, brown |
| 17 | 170.0 | 338.0 | 20.2 | well done, brown |
| 17 | 170.0 | 338.0 | 21.2 | well done, brown |

½ cup of water,
½ cup of milk,
1 teaspoonful of lard,
¼ teaspoonful of salt,
1 tablespoonful of sugar,
enough hard wheat flour to make a soft dough,
yeast.

In the bread experiments the most satisfactory results were obtained above 180°C. (356°F.). At the lower temperature the crust was hard and thick due to excessive evaporation of moisture as indicated by the loss in weight curve. At 240°C. (464°F.) the outside of the loaf had a tendency to brown over before the inside was thoroly done. So many factors other than the time and temperature of baking affect the texture and quality of the bread that no attempt was made to accurately score the loaves baked. The quality of flour, the proportion of the ingredients, and the manipulation before baking[1] all affect the flavor, quality, and texture of the loaf. It may be stated, however, that the range of temperature for baking bread in the above sized loaves lies between 180° and 240°C. The size of pan used was smaller than is used in the average household and the time required for baking a larger loaf would be somewhat longer.

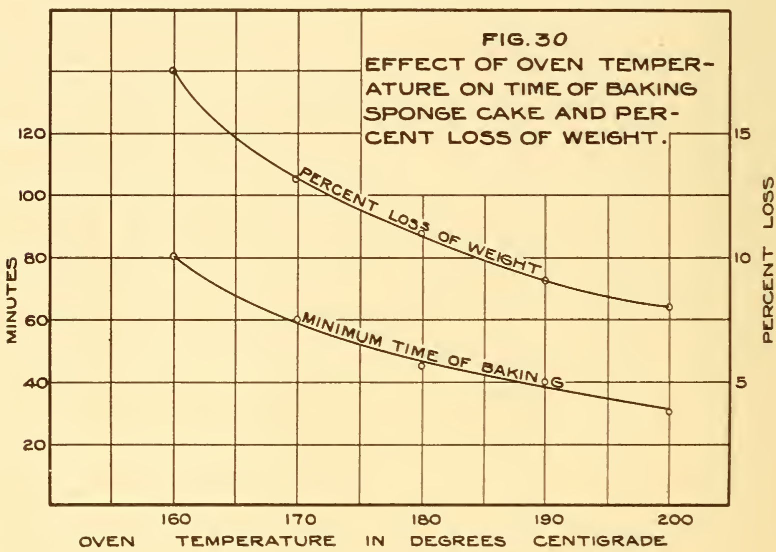


Fig. 30 shows the minimum time of baking and the per cent loss of weight curves for the sponge cake tests. The cake was prepared according to the following recipe:

4 eggs,
1 cup of sugar,
1 cup of flour,
1 tablespoonful of lemon juice.

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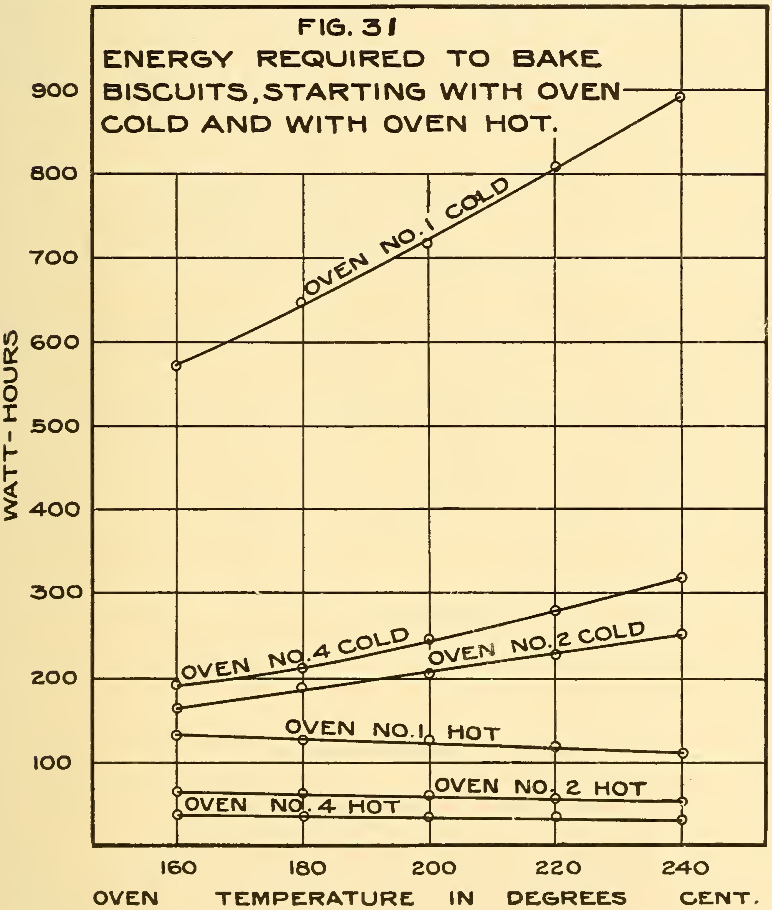
1. Univ. of Ill. Bull. Vol. X, No. 25.

The loaves averaged 250 grams in weight and were baked in a tin dish of the following dimensions: 5.5 inches by 4.2 inches by 2.5 inches deep.

The lowest temperature that should be used for baking sponge cake is approximately 170°C. (338°F.) as the crust becomes very heavy and thick at the lower temperatures due to the long baking and

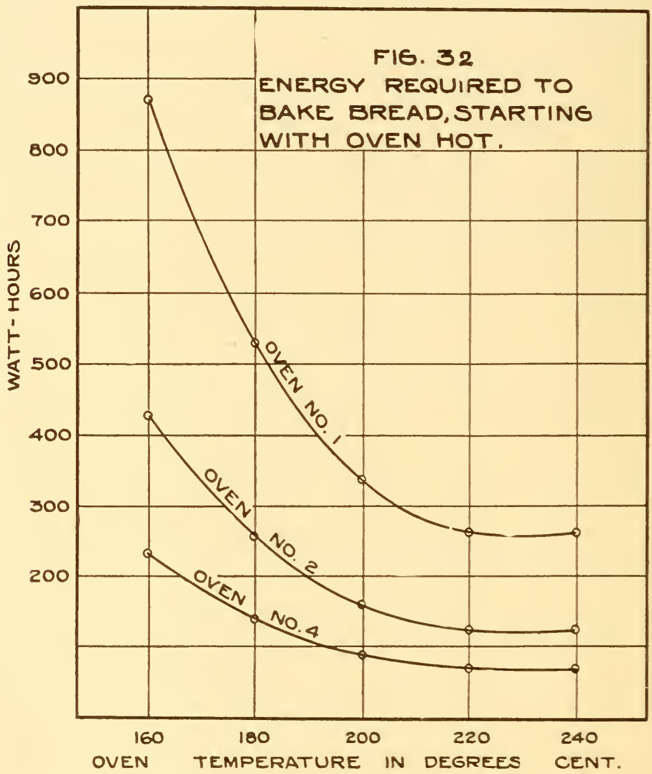
FIG. 31
ENERGY REQUIRED TO BAKE BISCUITS, STARTING WITH OVEN COLD AND WITH OVEN HOT.




the large loss of moisture. Because of the larger proportion of liquid in the dough, sponge cake will stand a greater loss of moisture than bread or biscuits. At 200°C. (392°F.) the loss of moisture was evidently too small as the texture of the crumb was not as good as the

samples baked at lower temperatures. The range of temperature, therefore, for baking sponge cake lies between 170° and 200°C. (338° and 392°F.).

The curves of Fig. 31 show the amount of energy used in baking biscuits at the various oven temperatures for ovens Nos. 1, 2, and 4 with and without preheating. The curves show that if biscuits are baked immediately after other food is removed from the oven so that preheating is not necessary the energy required will be very small compared to the amount required if the oven has to be heated up from room temperature to baking temperature. This is especially true of




oven No. 1. When the baking is begun with the oven already at the desired temperature, the energy used in baking biscuits is practically the same for all the temperatures tried; but when the oven has to be heated up from room temperature the energy used is considerably less at the lower temperatures. Since the quality of the biscuits baked at temperatures below 200°C. (392°F.) is not as satisfactory as at higher

temperatures, these temperatures are not recommended. Two hundred degrees Centigrade is, therefore, the most economical temperature for baking biscuits when preheating is necessary.

Because the conditions of baking biscuits satisfactorily are a high temperature for a short time, the greater part of the energy required will be used in preheating. Consequently ovens used for baking biscuits should require as little energy as possible for preheating. This

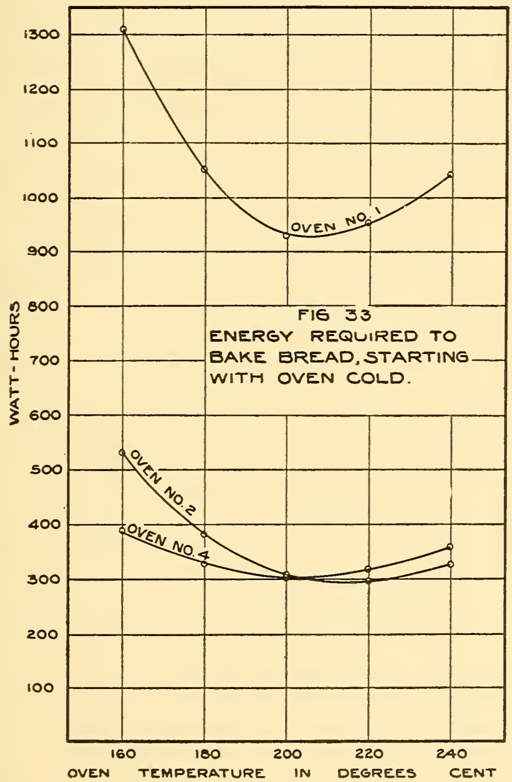


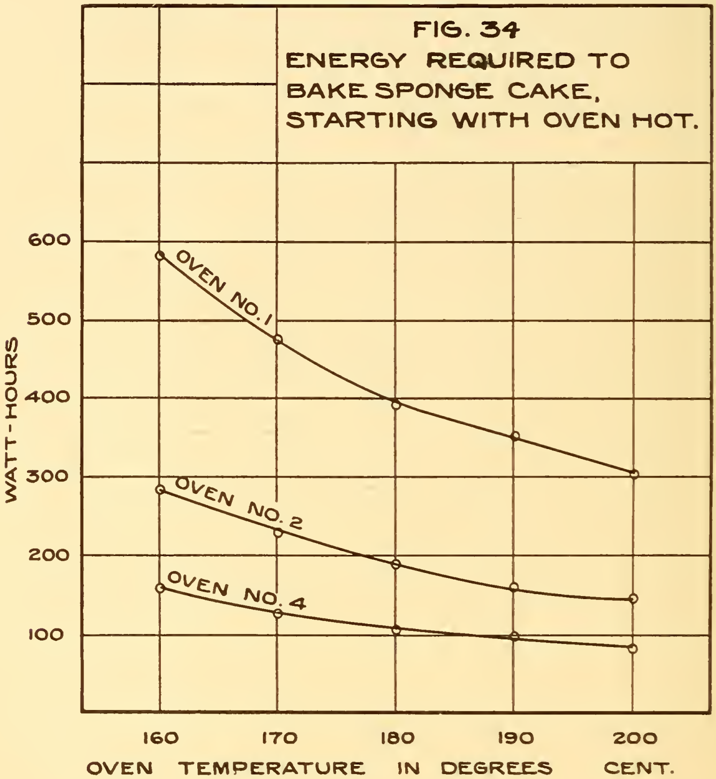

FIG 33
ENERGY REQUIRED TO BAKE BREAD, STARTING WITH OVEN COLD.

can be accomplished to a certain extent by using as small an oven as is practical.

Biscuit samples were also baked in ovens Nos. 2, 3, and 4. In oven No. 2 the biscuits did not brown satisfactorily on top as there was no heating element in the top of the oven. Oven No. 3 was found to be unsatisfactory for baking biscuits because with the heating arrangement used it was difficult to get sufficiently high temperatures. The

biscuits baked in oven No. 4 were quite satisfactory. The time of baking and the per cent loss of weight checked with the values obtained for oven No. 1.

The curves of Fig. 32 show the amount of energy used in baking bread at the various oven temperatures without preheating. It will be noticed that for all the ovens the energy required is a minimum above




220°C. (428°F.). The most economical temperature for baking bread when the oven is already heated is, therefore, from 220° to 240°C. (428° to 464°F.).

The curves of Fig. 33 show the amount of energy used in baking bread at the various oven temperatures including preheating. The temperature for which the energy required becomes a minimum lies between 200° and 215°C. (392° to 419°F.) depending on the oven

used. Altho the insulation of oven No. 4 is very much better than that of oven No. 2, it will be noticed that above 205°C, oven No. 4 requires more energy for baking bread than oven No. 2. This is due to the larger amount of energy required for the preheating.

The curves of Figs. 34 and 35 show the amount of energy used in baking sponge cake at the various temperatures with and without

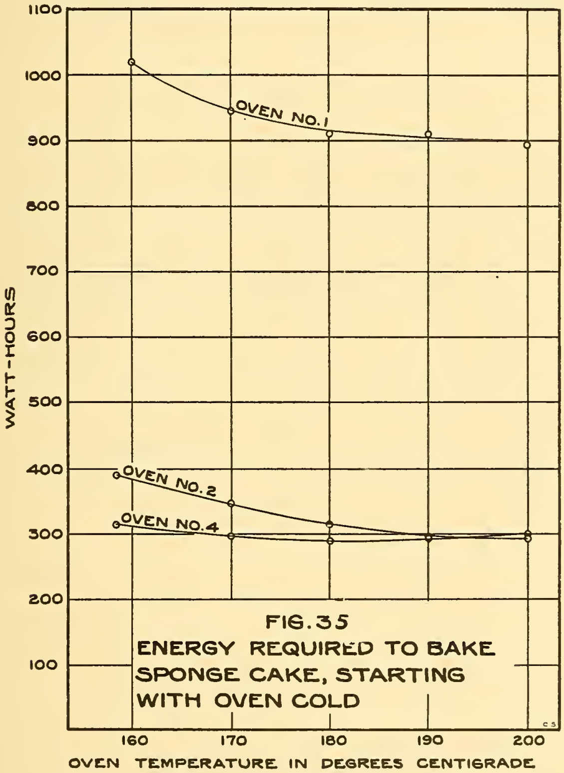



FIG. 35
ENERGY REQUIRED TO BAKE SPONGE CAKE, STARTING WITH OVEN COLD

preheating. As shown by the curves, the most economical temperature for baking sponge cake, when the oven is already heated, is 200°C. Except for oven No. 4 this is also the most economical temperature when the oven is started at room temperature. For oven No. 4, the most economical temperature is 180°C. but the difference in the energy required at 180° and 200°C. is slight. Because of the poorer quality obtained at 200°C, the best temperature for baking sponge cake will be between 180° and 190°C.

Consideration of the baking curves as a whole will emphasize the importance of the preheating characteristics in designing an efficient electric oven. For the kinds of baking which require a high temperature for a short time the preheating loss is considerably greater than the radiation and convection loss. Unless some method can be found for decreasing the energy used in heating the oven up from room temperature it will not be practical to increase the heat insulation of the ovens used for domestic baking. This does not apply, however, to ovens which are used for long intervals at the same temperature.

## THICKNESS OF HEAT INSULATION

If a heat insulating material is placed between the inner and the outer surfaces of an electric oven, the radiation and convection losses will be reduced, due to the lower temperature of the outside surface, as explained in a previous paragraph. For the same internal temperature of the oven, the greater the thickness of insulation used, the lower will be the temperature of the outside surface and the smaller will be the losses. It would not be economical, however, to increase very greatly the thickness of the heat insulation as the cost of each additional inch increases rapidly and the effect of each additional inch on the amount of energy lost decreases even more rapidly. If, for a given insulating material, the number of hours per year that the oven will probably be used at the various oven temperatures and the cost of electricity are known, there is, evidently, a definite thickness of heat insulation for which the sum of the cost of the energy lost per year due to the radiation and convection and the annual cost of the insulation will be a minimum.

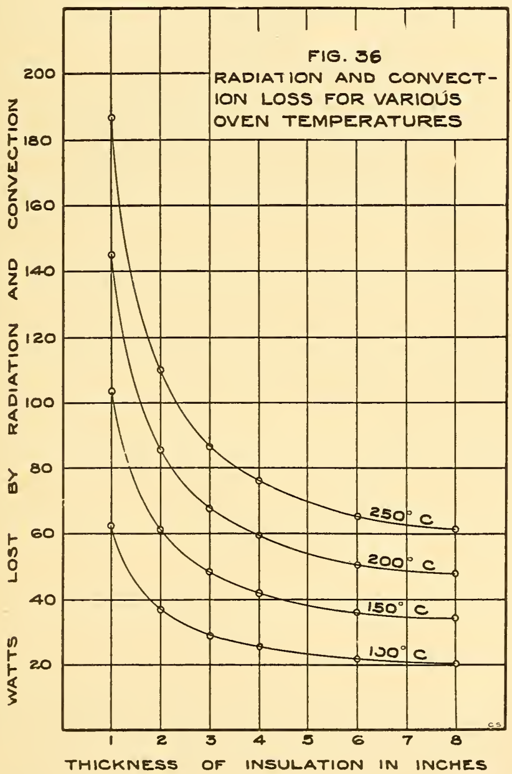
In order to obtain some data on the most economical thickness of heat insulation for electric ovens a series of experiments were undertaken. From one to eight inches of powdered kieselguhr was used for the heat insulation. A heating element and a thermo-couple were placed in a tin box 9 inches by 10.5 inches by 12 inches, which were the inside dimensions of ovens Nos. 2 and 4. This box was placed inside a larger box and the space between the two was filled with the insulating material. Care was taken to center the inner box accurately so as to obtain a uniform thickness of insulation on all sides. The insulation was packed gently and uniformly so that the density obtained was approximately twenty pounds per cubic foot.

The method used in each test was to connect the heating element to a source of constant potential and leave it until the inside temperature of the oven reached a constant value, when readings were taken of watts input and the oven temperature.

A copper constantan thermo-couple which had been calibrated by the Bureau of Standards was used to measure the oven temperature.

During the first part of each test it was connected to a Bristol recording galvanometer. After the internal temperature had remained constant for at least three hours the thermo-couple was connected to a potentiometer, by means of which the e. m. f. of the couple was accurately obtained. The cold junction was kept at 0°C. (32°F.) by immersion in ice water.

During the first few hours of each test the heating element was connected to the laboratory supply mains while for the last six hours of each test it was connected to a motor generator set, the voltage of




which was kept constant by means of a Tirrill regulator. Energy input was obtained from the readings of a voltmeter and an ammeter which had been carefully calibrated by comparison with Weston laboratory standards. The kind of external surface used in each test was new bright tin. The bottom surface rested on a cement floor.

The results of the experiments are given in Table IX since for a given thickness of heat insulation and low temperature of external oven surface the radiation and convection loss is approximately proportional to the difference between the room temperature and the inside temperature of the oven as shown in Fig. 11,—the loss for any oven temperature can be calculated. The curves of Fig. 36 show the relation between the thickness of insulation and the watts lost for oven temperatures of 100°, 150°, 200°, and 250°C. (212°, 302°, 392° and 482°F.).

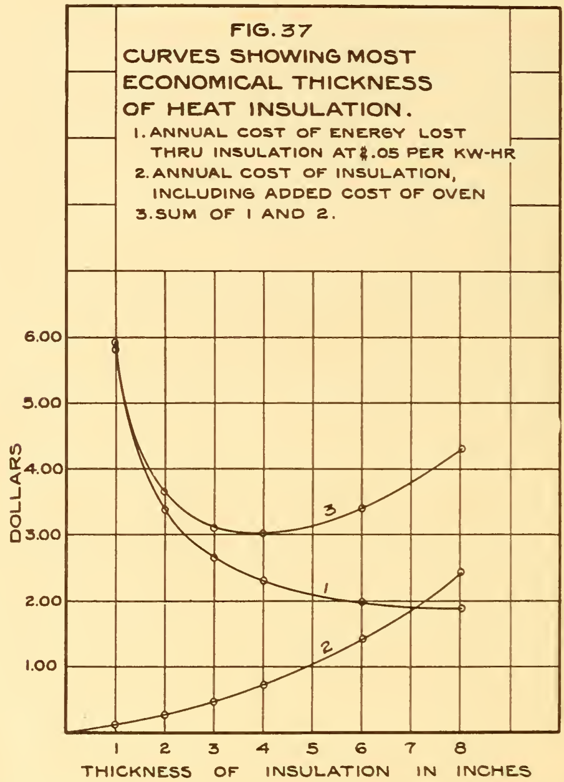



FIG. 37
CURVES SHOWING MOST ECONOMICAL THICKNESS OF HEAT INSULATION.
1. ANNUAL COST OF ENERGY LOST THRU INSULATION AT $.05 PER KW-HR
2. ANNUAL COST OF INSULATION, INCLUDING ADDED COST OF OVEN
3. SUM OF 1 AND 2.

If the number of hours per year that an oven of this size will be used at the various oven temperatures can be estimated, the cost per year of the radiation and convection losses can be calculated from these curves. In order to get a value for the most economical thickness of heat insulation, it is assumed that an oven of this size is to be used as follows:

100 hr. per yr. at 200°C. (392°F.)
150 hr. per yr. at 175°C. (347°F.)
400 hr. per yr. at 150°C. (302°F.)
750 hr. per yr. at 125°C. (257°F.)

It is also assumed that the cost of electricity for cooking is 5 cents per kilowatt-hour.

Curve 1, Fig. 37 shows the cost per year of the radiation and convection loss for various thicknesses of insulation. Curve 2 shows the cost of heat insulation used, at 2 cents per pound and twelve pounds per cubic foot. An accurate expression for the cost of adding extra insulation should include the extra cost of the outside covering of the

Table IX.

| Thickness of insulation, in. | Internal temp. degrees | | Room temp. degrees | | Watts loss |
|---|---|---|---|---|---|
| | Cent. | Fahr. | Cent. | Fahr. | |
| 8 | 271.1 | 520.0 | 24 | 75.2 | 67.4 |
| 8 | 271.0 | 519.8 | 25 | 77.0 | 67.4 |
| 6 | 270.5 | 518.9 | 27 | 80.6 | 70.6 |
| 6 | 271.0 | 519.8 | 26 | 78.8 | 71.0 |
| 4 | 233.1 | 451.6 | 25 | 77.0 | 71.2 |
| 4 | 237.8 | 460.0 | 25 | 77.0 | 71.4 |
| 3 | 210.4 | 410.7 | 26 | 78.8 | 71.7 |
| 3 | 210.2 | 410.4 | 27 | 80.6 | 71.7 |
| 2 | 170.6 | 339.1 | 25 | 77.0 | 69.4 |
| 2 | 171.8 | 341.2 | 25 | 77.0 | 72.1 |
| 1 | 106.5 | 223.7 | 24 | 75.2 | 67.6 |
| 1 | 106.3 | 223.3 | 25 | 77.0 | 67.5 |

oven, necessitated by the extra volume of insulation. As no data are available to the author concerning the cost of manufacture, it is assumed that for each thickness of insulation the manufacturing cost of parts of the oven affected by the thickness of insulation is three times the cost of the insulation itself. If an interest and depreciation charge of 25 per cent is assumed, curve 2 becomes the cost per year of insulating this size oven with various thicknesses of heat insulation. It is evident that for the most economical thickness of heat insulation the sum of curve 1 and curve 2 should be a minimum. This condition

is fulfilled for an insulation thickness of four inches as shown by curve 3.

In a similar manner the most economical thickness of heat insulation for any given set of conditions can be determined. A limiting factor other than the cost of the insulation is the rapid increase in the size of the oven for the larger thicknesses. It is unlikely that insulation thicknesses more than four inches will be used for domestic purposes; because, for thicknesses above this value, the ovens become too large and cumbersome to use in the ordinary kitchen.

The results of the experiments just described indicate that a net annual saving would result if the commercial electric ovens now on the market were better insulated. There are several electric ovens now on the market which have as small as one inch of heat insulation. Even under the most favorable conditions this could probably be economically increased to two or three inches.

An objection that the designer of electric ovens may bring against an increase in the thickness of heat insulation is the danger to the oven if the automatic cut off fails to operate. The ovens now on the market are built to withstand the highest oven temperature obtainable with all the coils turned on full. This design is necessary at present because of the lack of a cheap and reliable automatic release. As an auxiliary to a mechanical release, a heat fuse might be constructed so as to melt due to the internal temperature of the oven if the mechanical release failed to operate. For ovens operating at 100°C. (212°F.) or less, pure tin might be used and zinc for ovens using higher temperatures. Even if the retail price of such a fuse should be high, their use would not be prohibitive as they would blow only when the automatic release failed to work.

Kieselguhr was chosen as the heat insulating material in the above experiments as it is the cheapest of the good heat insulators which will stand medium high temperatures; its melting point being[1] 1610°C. (3930°F.).

Of other materials used for heat insulation of electric ovens silox, mineral wool, and non-pareil insulating brick also give good results. No experiments were made by the author, however, to determine the relative advantages of each. Cork board was used on one of the experimental ovens constructed; but altho it is a very good heat insulator it is not to be recommended for oven temperatures above 100°C. (212°F.) on account of its combustibility.

1. Met. & Chem. Engr., vol. 12, p. 112.

## SUMMARY

1. The radiation and convection loss from an insulated electric oven can be obtained for any oven temperature below 250°C. (482°F.) by measuring the maximum temperature of the oven for a given energy input plotting these values and drawing a straight line thru the point thus obtained and zero energy at room temperature.

2. The preheating loss of an electric oven can be obtained by taking simultaneous readings of watt-hours and oven temperature. For domestic use the preheating loss should be made as small as possible by decreasing the heat capacity of the oven as much as is practical and by using a large coil for the preheating.

3. The energy lost when the door of an electric oven is opened for fifteen seconds was determined for various oven temperatures. For an oven temperature of 200°C. (392°F.) used in baking bread, biscuits, etc. the loss due to opening a 12-inch by 18-inch oven door for fifteen seconds amounted to twelve watt-hours. At 5 cents per kilowatt hour for electric current this would mean a cost of six one-hundredths of a cent each time the door was opened for a period of fifteen seconds. (See Fig. 15.)

4. Since the purpose of cooking food is not to put as many heat units as possible into the food but is rather to improve its flavor and to increase its digestibility, the steam boiler method of determining efficiency is not applicable to electric ovens.

5. In order to compare the cost of cooking in various electric ovens a method proposed for indicating the relative efficiency of the electric ovens is to specify the amount of the preheating and the radiation losses at the required oven temperatures.

6. The time required for roasting a rolled rib roast of beef, rare, medium rare, and well done, was determined for various oven temperatures. The shortest time of roasting was at 160°C. (320°F.). (See Fig. 17.)

7. The per cent loss of weight of the roasts was found to increase with the oven temperature used. (See Table V.)

8. The energy required for roasting a rolled rib roast of beef in three types of electric ovens was determined for oven temperatures from 100° to 180°C. (212° to 356°F.). The most economical temperature for preparing rare and medium rare roasts was found to be 100°C. in each oven. For well done roasts 120°C. (248°F.) is the most economical temperature.

9. With electricity at 5 cents per kilowatt hour, it is at least 2 cents cheaper to roast beef at 100° to 120°C. than at 180°C.

10. It was found that at least 1000 watt-hours could be saved by searing the roast on top of the stove instead of heating the whole oven up to 250°C., a saving of five cents on the basis of 5 cents per kilowatt hour for electric current.

11. A method was devised for determining the most economical temperature for baking bread, cake, and biscuits. The minimum time of baking and the per cent loss of weight were determined for several oven temperatures. (See Table VIII.)

12. The range of oven temperatures for baking biscuits was found to be from 200° to 240°C. (392° to 464°F.). Starting with the oven at the required temperature, the energy used in baking biscuits is practically the same for all oven temperatures. If it is necessary to heat up the oven from room temperature the most economical oven temperature is the lowest which will give satisfactory results; i. e. about 200°C. (392°F.).

13. The range of temperatures for baking a small sized loaf of bread was found to lie between 180° and 240°C. (356° and 464°F.). Starting with the oven at the required temperature the most economical temperature for baking bread is between 220° and 240°C. When preheating is included, the most economical temperature for a small sized loaf was found to be between 200° and 215°C.

14. The range of temperature for baking sponge cake was found to lie between 170° and 190°C. (338° and 374°F.). For baking sponge cake the most economical oven temperature is the highest temperature which will give satisfactory results; i. e., about 190°C. (374°F.).

15. With electricity at 5 cents per kilowatt hour and allowing an interest and depreciation charge of 25 per cent, the most economical thickness of kieselguhr insulation was found for domestic use to lie between three and four inches.

## CONCLUSIONS

Much has been accomplished recently by domestic scientists in substituting accurate scientific methods of cooking for the vague and indefinite rules of our grandparents. There is, however, an enormous amount of work yet to be done before an inexperienced person can hope to get uniformly good results without first experiencing many failures and wasting much good material.

With reference to the use of a thermometer for the standardization of oven temperatures Miss M. B. Van Arsdale,[1] assistant professor of household arts at Columbia University, says, "Regarding the inexperienced housewife it can truly be said that with an accurate thermometer her results would undoubtedly be more uniformly good—and we believe that the recipe books of the future should not read merely 'bake until done in a moderate oven' or 'according to judgment,' but will also state how long and at what temperature, so that in the hands of even the inexperienced these recipes will yield not occasionally good

1. Technical Educ. Bul. No. 22, Columbia Univ.

but uniformly good results without the discouragement of many failures, the sacrifices of much time and the waste of much good material. Thus the scientific treatment of the subject added to our traditional knowledge should tend to evolve an even higher type of cookery than we have had in the past."

The present lack of definite rules for cooking is due in a large degree to the absence of adequate means of controlling the temperature of the food. When using the ordinary wood or coal cooking range the degree of heat is controlled chiefly by dealing with the food itself rather than by regulating the heat at the point of combustion. The amount of draft necessary to promote the combustion of the fuel causes too great a degree of heat in the oven or on the stove to enable the cook to deal with the food in the proper way except by constantly watching it, stirring it, and changing the position of the vessel on the stove or in the oven.

With the advent of electric ovens a revolution in the methods of cooking has become possible. Not only can the temperature of the electric oven be accurately controlled but the necessity of constant vigilance is removed. Apparatus can be designed for making the whole process practically automatic. Some kinds of food can even be prepared in advance, placed in the oven, and without any further attention on the part of the housewife the current will automatically be turned on at a predetermined time. The temperature of the oven will increase to the desired value and there remain constant until the food is properly cooked.

With this method perfected the advantage of electric cooking over the other methods will be great and in most cases the cost will not be excessive. To the possibility of obtaining uniformly well-cooked food should be added the saving to the housewife in time and worry and the absence from the kitchen of excessive heat.

The present day problem in electric cooking is to determine the methods of cooking that will yield the most in nutrition and flavor and to formulate definite rules or directions so that a particular article of food can be cooked in the best possible manner by persons of ordinary skill. The engineer's problem is then to design practical cooking devices in which the temperature can be accurately regulated with a minimum of attention on the part of the housewife.

Electric cooking may be classified according to the temperature to be used in the oven. The baking of bread, cake, and pastry requires a high oven temperature. In the average family where the oven is used intermittently a large part of the electricity used in this class of baking will go to heat up the oven from room temperature to the required baking temperature. In other words the preheating loss will be large compared with the radiation and convection loss.

The preparation of vegetables, cereals, and meats (except for searing, broiling, and frying) requires a low degree of heat, applied

for several hours. In this class of cooking the preheating loss forms but a small part of the total loss, while the radiation and convection loss is a large part of the whole.

It is evident that the characteristics of properly designed ovens differ for the two kinds of cooking. An oven to be used for baking at the high temperature should have the preheating loss reduced to a minimum. A large-sized heating element should be used for the preheating and be automatically cut off as soon as the oven reaches the desired temperature. A smaller coil will then suffice to keep the oven at the required temperature by supplying enough heat to balance the losses and the heat absorbed by the food. Unless it is planned to frequently use the oven for several hours at the same temperature as in baking several batches of bread or cake, it will not pay to increase the heat insulation of the oven to such an extent as where the preheating loss is smaller. Since in cooking at the lower temperatures, the preheating loss is small compared with the radiation and convection loss, the latter then becomes the more important and a thicker heat insulation can be economically used.

For baking at the higher temperatures a heating element in the upper part of the oven is necessary to get the best results. Without the upper heating coil the bread, cake or biscuits will burn on the bottom before they are satisfactorily browned on top. For the lower temperatures this upper coil is unnecessary.

Furthermore, for baking at the higher temperatures, the food and the heating coil must be separated several inches with a baffle between to secure more uniform heating and to prevent burning on the bottom. This arrangement, tho necessary, results in poor heat conductivity between the heating element and the food. Hence, more energy will be required as indicated in the tests in heating water in the oven and on top of the stove. Since in cooking at the boiling point or below the food can be partly immersed in water, there is not the danger of burning as in baking. The baffle over the heating coil can, consequently, be dispensed with and the vessel of food can be placed directly on the heating element. A much better heat conductivity between the food and the heating element will result. Less energy will be required for the first part of the cooking process when the food is being heated from the room temperature to the required cooking temperature.

As the size of an electric oven greatly affects the amount of the losses, an oven should be made as small as is practical for the size of the family that is to use it. For instance, oven No. 1 is uneconomical for a small family as several loaves of bread, cakes or tins of biscuits can be baked in it for the cost of one. For cooking at the lower temperatures the oven can be made smaller than for baking at the high temperatures as there is not the danger of the food burning due to non-uniform heating. For this class of cooking the utensils can

fit snugly into the oven so that the size of the oven can be reduced to a minimum.

The increased popularity of the fireless cooker indicates that people are learning that food can be cooked at temperatures lower than the boiling point of water. The particular temperature of 100°C. (212°F.) has long been the one used for cooking cereals, vegetables, and meats. This is because it is the easiest temperature to maintain at a constant value and not because it necessarily gives the best possible results. The fact that several hours are required for the cooking at lower temperatures is not a disadvantage when the process is automatic and does not require the attention of the housewife. Aside from the question of the quality of the food and the saving in electricity, four hours would probably be the most convenient time to allow for cooking food. The housewife could put in the food for the midday meal immediately after breakfast while the oven was still hot. When it was taken out she could put in the evening meal so that the oven would be used continuously. The preheating loss would thus be reduced to a minimum. During the latter part of the afternoon the housewife would not need to be tied to her kitchen, since all that would be necessary at this time would be to dish up the food and serve it.

The electric light and power companies should be interested in perfecting this method of cooking and in bringing it to the attention of their customers. A combination of the electric oven and the popular fireless cooker would be a very desirable load for the central station. It would be a steady all day load and would not interfere with the peak load even in the winter; as enough heat can be stored in a well-insulated oven to keep the food sufficiently hot for an hour or more after the current is turned off.

The results of the cooking experiments in electric ovens indicate that it is possible to reduce the art of cooking to an exact science. If definite rules of time and temperature were formulated for cooking each article of food, the inexperienced housewife could obtain uniformly good results with the expenditure of a minimum amount of attention and fuel.

The requirements for an electric oven for baking at the higher temperatures are,—minimum heat capacity of the oven, a large heating unit to heat up the oven from room temperature, an automatic device to cut out this heating unit as soon as the oven reaches the desired temperature, smaller heating coils to maintain the temperature at the desired value, a heating unit in the upper part of the oven, a baffle above the lower coils to distribute the heat, as small an oven as is practical for the size of family using it, and from two to four inches of heat insulation.

The requirements of an electric oven for cooking at the lower temperatures are,—from three to four inches of heat insulation, a simple device for automatically controlling the temperature, a large coil for

heating up the food from room temperature, placing the vessels of food directly on the heating units whenever possible, and a size of oven only large enough to contain the utensils to be used.

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EDITED BY

E. J. McCAUSTLAND

*Dean of the Faculty of Engineering, Director of the Engineering Experiment Station*

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